EXHIBIT D

Expert Report of Lisa A. Rodenburg, Ph.D.

City of Spokane v.
Monsanto Company, et al.

Submitted by Lisa A. Rodenburg, Ph.D.
Octobert 11, 2019

Fingerprinting of PCB congener patterns in samples from the Spokane, WA area

Lisa A. Rodenburg

Qualifications

I am a Professor of Environmental Science at Rutgers, the State University of New Jersey. I have a BA in chemistry from Wittenberg University and a PhD in Environmental Engineering from the Johns Hopkins University. I have been studying PCBs since 1998 when I began a post-doctoral fellowship at Rutgers with Dr. Steven Eisenreich, a noted PCB expert. I have extensive experience measuring PCBs in environmental samples in an academic laboratory using methods similar to EPA methods 8082 and 1668, and in interpreting PCB data from these two methods.

I have pioneered the use of factor analysis, specifically Positive Matrix Factorization, to understand the sources of PCBs to complex ecosystems that may have multiple potentially responsible parties (PRPs) and display a variety of PCB weathering processes. I used the methods described here (analysis of data sets with the PMF2 software) to investigate several systems resulting in multiple peer-reviewed publications and reports, including:

- The Delaware River (air, water, sediment, and permitted discharges) with funding from the Delaware River Basin Commission and the New Jersey Department of Environmental Protection (Du and Rodenburg, 2007a; Du et al., 2008; Du et al., 2009; Rodenburg et al., 2010a; Praipipat et al., 2013; Praipipat et al., 2017).

- The New York/New Jersey Harbor (air, water, sediment, and permitted discharges) with funding from the Hudson River Foundation (Rodenburg et al., 2011; Rodenburg et al., 2012; Rodenburg and Ralston, 2017).

- The Green-Duwamish River (atmospheric deposition, water, sediment, biota, and storm water) with funding from the State of Washington in a project overseen by the US EPA (Rodenburg and Leidos, 2017b, a).

- The Portland Harbor Superfund Site (water and sediment) (Rodenburg et al., 2015c).

- The city of Chicago (atmospheric deposition) (Rodenburg and Meng, 2013).

- The Hanford Site in Hanford, Washington (biota) (Rodenburg et al., 2015a).

In these studies, I have identified PCB sources that are not related to Aroclors or other intentionally–produced commercial PCB formulations, including PCBs generated inadvertently during various chemical processes such as the production of pigments, as well as the dechlorination of parent PCB congeners (most likely arising originally from commercial formulations) by bacteria. As a result, I am recognized as an international expert in non-commercial PCB sources, having published several peer-reviewed papers on this subject

(Rodenburg et al., 2010b; Guo et al., 2014; Rodenburg et al., 2015b). I served as an expert witness on this subject for the State of Washington (Department of Ecology) at the August 2012 meeting of the Environmental Council of States. My research on this subject led to my appearances on Good Morning America in 2014 and news coverage in outlets such as Scientific American, Environmental Health Perspectives, Environmental Health News, and Yahoo! News.

My expertise on the subject of PCB sources and fate has been recognized by the Hudson River Foundation, where I serve as a member of their Science and Technical Advisory Committee for the New York/New Jersey Harbor & Estuary Program. I am currently an advisor to the Spokane River Regional Toxics Task Force (SRRTTF). I have also served on the Expert Panel advising the Delaware River Basin Commission on establishment of a Total Maximum Daily Load (TMDL) for PCBs in the Delaware River.

For additional qualification information, see my CV attached as Exhibit A.

Compensation

My general billing rate is $200 per hour. My rate for testimony is $300 per hour.

Testimony in Past 4 Years

City of Hartford, et al. v. Monsanto Company, et al. – February 7, 2018

City of San Diego, et al. v. Monsanto Company, et al. – June 14, 2019

Summary of opinions

In my expert opinion, commercial PCBs (Aroclors), and not byproduct PCBs, are the main sources of PCBs to all of the environmental compartments in and around the Spokane River and associated watershed for which we have data.

Through my analysis, as discussed throughout this report, I have developed the following opinions, discussed here by environmental compartment. In all compartments, Aroclors are the dominant source of PCBs. The following compartments were investigated using PMF (Positive Matrix Factorization):

- In surface water samples collected by the SRRTTF, commercial PCBs make up about 90% of the total PCBs present.
- In samples from the sewer system of the Spokane City WWTP, which includes both plant influent and CSOs, commercial PCBs on average make up over 95% of the total PCBs detected.
- In the water column, commercial PCBs make up about 90% of the total PCB mass on average.

- In tissue from fish caught in the Spokane River in the vicinity of the city of Spokane, commercial PCBs account for virtually all of the PCBs detected. Non-commercial PCBs make up less than 1% of the total PCBs detected.
- In stormwater samples from the city of Spokane, commercial PCBs comprise over 95% of total PCBs, on average.
- In groundwater at the Kaiser facility, commercial PCBs account for virtually all of the PCBs detected.
- In outfalls at the Kaiser facility, commercial PCBs make up about 98% of total PCBs.

The following compartments were investigated using MLR (Multiple Linear Regression):

- Two CSO samples were collected using a different method than other CSO samples and must be analyzed separately. In those samples, commercial PCBs made up over 99% of the total PCBs present.
- Twenty-three stormwater samples were collected using a different method than other stormwater samples and must be analyzed separately. In those samples, commercial PCBs made up over 95% of the total PCBs present.
- In eight samples of solids from storm drains and collection basins, commercial PCBs make up more than 95% of total PCBs on average.
- In treated effluent from the City of Spokane's WWTP, commercial PCBs made up more than 90% on average of total PCBs.
- In bulk atmospheric deposition samples collected in and near Spokane, Aroclors were the dominant sources of PCBs. The contribution of non-commercial PCBs to the atmospheric deposition was difficult to quantify due to probable blank contamination, but is certainly less than 50%.
- In samples of biofilm and caddis and mayfly larvae collected in the Spokane River, commercial PCBs make up about 90%, on average, of total PCBs.
- In river sediment from the Spokane River near Spokane, commercial PCBs were more than 95%, on average, of total PCBs.
- In groundwater from the GE facility, commercial PCBs account for virtually all PCBs detected.
- In samples from the Inland Empire Paper wastewater treatment facility, commercial PCBs comprised more than 80% of total PCBs on average.
- In surface water sampled using the CLAM device, commercial PCBs comprised about 90% of total PCBs.

In municipal products tested by the City of Spokane, Aroclor PCBs were sometimes present, indicating that not all PCBs detected in consumer products can be assumed to arise from non-commercial sources.

Introduction

Samples of a wide variety of environmental compartments in the Spokane, WA area were analyzed for this report. The purpose of this work was to examine the congener patterns in these samples in an attempt to determine whether the PCBs in these samples arose from Aroclors produced by Monsanto, and if so to quantify the fraction of the total PCBs in each sample that is attributable to Aroclors versus the fraction attributable to non-Aroclor sources.

As explained in more detail below, I used two types of analysis for this project: Positive Matrix Factorization (PMF) and Multiple Linear Regression (MLR). PMF is the primary technique used here, but for certain samples insufficient data required MLR analysis. For the following environmental compartments, I conducted a PMF analysis:

- Surface water
- Spokane City WWTP influent and CSOs
- Fish
- Stormwater
- Kaiser groundwater
- Kaiser outfalls

For the following environmental compartments, the quantity of data was not sufficient for PMF analysis, so these compartments were analyzed using Multiple Linear Regression (MLR):

- Two samples from CSOs measured using a DB5 column
- Twenty-three samples of stormwater measured using an SPB-octyl column
- Spokane City WWTP treated effluent
- Bulk Atmospheric Deposition
- Biofilm
- Sediment (including suspended particulates)
- Surface water CLAM (Continuous low-level aquatic monitoring) samples
- Groundwater from the GE plant
- Inland Empire Paper outfalls
- Storm drain solids
- Municipal products

These data have been collected under various Quality Assurance Project Plans (QAPPs). Data was obtained from two main sources. The first was the database provided by Baron and Budd. Version 20 was used for all analyses in this report. Data were blank corrected before being entered into this database. The second source was the SRRTTF, which provided various data in the form of Excel spreadsheets. This data underwent Quality Assurance checks. In each of the SRRTTF data sets, data was provided as “MEL amended” results, which were blank corrected. These MEL amended results were used for all analyses.

Background on PMF

The primary technique used here is factor analysis using Positive Matrix Factorization (PMF) (Paatero and Tapper, 1994). This approach has been used extensively in the environmental literature to investigate PCB sources by the author of this report (Du and Rodenburg, 2007b; Du et al., 2008; Rodenburg et al., 2010a; Rodenburg et al., 2011; Rodenburg et al., 2012; Praipipat et al., 2013; Rodenburg and Meng, 2013; Rodenburg et al., 2015a; Rodenburg et al., 2015c; Praipipat et al., 2017; Rodenburg and Ralston, 2017) and many other researchers (Magar et al., 2005; Bzdusek et al., 2006a; Bzdusek et al., 2006b; Soonthornnonda et al., 2011; Uchimiya et al., 2011; Saba and Su, 2013; Karakas et al., 2017).

PMF defines the sample matrix as product of two unknown factor matrices with a residue matrix:

$$X = GF + E \quad (1)$$

The sample matrix (X) is composed of n observed samples and m chemical species. F is a matrix of chemical profiles of p factors or sources. The G matrix describes the contribution of each factor to any given sample, while E is the matrix of residuals. The PMF solution, i.e. G and F matrices, are obtained by minimizing the objective function Q through the iterative algorithm:

$$Q = \sum_{i=1}^{n}\sum_{j=1}^{m}(e_{ij} / s_{ij})^2 \quad (2)$$

Q is the sum of the squares of the difference (i.e. e_{ij}) between the observations (X) and the model (GF), weighted by the measurement uncertainties (s_{ij}). Here we have used the PMF2 software of Paatero and Tapper (1994).

The advantage of the PMF approach is that it can quantify the fraction of a given congener that comes from Aroclor versus non-Aroclor sources, and it does not make the assumption that no weathering of the PCB fingerprints has taken place. Instead it produces fingerprints of congeners that co-vary and have been found to be present in most of the samples. The user can then compare these fingerprints to the Aroclor patterns to determine whether they are similar to the Aroclors. In the PCB source evaluation project in the Green-Duwamish River system in Washington State (Rodenburg and Leidos, 2017a), the Washington State Department of Ecology accepted the interpretation that when the agreement (R^2) between the fingerprint produced by the PMF program and a single Aroclor is greater than approximately 0.8, the factor was considered to represent an unweathered single Aroclor. When the agreement was not as good (i.e., R^2 between approximately 0.4 and 0.8), the factor was interpreted as representing a weathered Aroclor. US EPA oversaw this project and did not object to this interpretation.

There are two main disadvantages of the PMF approach. First, the PMF program cannot find a stable solution when the input data contains too many values that are below detection limit (BDL). For this reason, congeners (or chromatographic peaks) that are frequently not detected

are removed from the data set prior to analysis. Second, the PMF program performs best when there are at least as many samples as PCB congeners (or peaks) in the input data set. As a result, the PMF approach requires a large number of samples to be effective. It is possible to include more congeners (peaks) than samples in the input, but if the number of peaks exceeds the number of samples by too wide a margin, the PMF program will be unable to find a stable solution. As a result of these two limitations, not all of the 209 PCB congeners will be considered in the PMF analysis, and therefore some of the PCB mass will not be considered. In addition, all of the samples included in a single PMF model must have the same coelution pattern. (This issue is described in more detail in the section on Measurement of PCBs below.) This means that data collected on one GC column (such as the SPB-octyl column) can only be combined with data collected using another column (such as the SGE-HT8) by pre-processing the data to sum some congeners so that both data sets will use a common co-elution pattern. Information is lost in the process. Also, all of the samples in a single PMF analysis should come from a set of samples collected in the same region and environmental compartment (i.e. water, sediment, etc.) so that they will have congener patterns in common. For example, in this report, fish samples are not combined with storm water samples for PMF analysis.

All data analysis approaches require that the input data be processed in some way. As noted above, the PMF approach requires that some congeners be discarded from the PMF input. In the sections below, I have indicated how much of the PCB mass had to be discarded when constructing the PMF inputs. Typically the fraction discarded is much less than 10%. Construction of the PMF inputs also requires that a proxy value be used in place of a zero for a value that is below detection limit. To do so, the operator must have some knowledge of the detection limits for each measurement. For all data sets analyzed using PMF in this report, non-detect values were replaced with a random number between zero and the LOD. Further, the PMF approach requires the user to estimate the uncertainty associated with each measurement. Usually the uncertainties for concentrations that are detected are calculated on a congener-by-congener basis from the relative standard deviation of the surrogate recoveries for each congener. When surrogate recovery information is not available, we have used uncertainties from a different but similar data set. For example, surrogate recoveries were not available for water and sediment data from the Portland Harbor Superfund Site, so the uncertainty matrices from the Delaware River water and sediment were substituted, respectively (Rodenburg et al., 2015c). Concentrations that were not detected were assigned three times the base uncertainty.

Non-commercial fingerprints from other data sets

The approach of using PMF2 analysis to identify PCB sources has been used in many previous studies that can be used to estimate the minimum contribution of non-commercial PCB sources that can be detected using the PMF approach. Table 1 summarizes the contribution of non-commercial PCB sources to various data sets investigated by the author of this report. In all cases, fingerprints identified in these studies as 'non-commercial' met the criteria enumerated above.

Table 2 suggests that the PMF analysis approach is capable of detecting a non-commercial fingerprint when it contributes as little as 1.1% of the PCB mass in the data set. To the extent that the data set is representative of the compartment (water, sediment) as a whole, this percentage can be interpreted as the contribution of the non-commercial source to all the PCB sources for that compartment. In five of the sixteen cases in which a non-commercial PCB factor was identified, the contribution of the non-commercial factor was equal to or less than 2%, suggesting that this approach can routinely identify contributions at this level.

For the present analysis, we conclude that for compartments in which a non-commercial factor was not isolated by the PMF analysis (i.e. fish tissue and Kaiser outfall), the contribution of non-commercial PCBs to that compartment is less than the contribution detected for the Spokane city storm water (6.5%) with a high degree of certainty, and is 2% or less with a reasonable degree of certainty.

Table 1: Non-commercial PCB factors isolated in other studies and their contribution to the mass in the data set.

Location	Matrix	Contribution of factor associated with:		Reference
		PCB 11	PCB 209	
Delaware River	Water	5%	19%	(Du et al., 2008)
	Sediment	1.4%	61%	(Praipipat et al., 2013)
	permitted discharges*	6.7%	1.5%	(Rodenburg et al., 2010a)
NY/NJ Harbor	Water	2.4%	none	(Rodenburg et al., 2011)
Portland Harbor Superfund Site	Water	6.3%	none	(Rodenburg et al., 2015c)
	sediment	1.1%	none	
Green-Duwamish River	atmospheric deposition	9%	4%	(Rodenburg and Leidos, 2017a)
	sediment	1.5%	none	
	stormwater solids	2%	8%	
	stormwater	4%	6%	

*For permitted discharges, the contribution represents the contribution to the total *load* of PCBs discharged from all facilities in the data set to the river. Load is calculated as concentration times flow, so facilities with larger flows will represent a larger contribution to the total load.

Background on MLR

The second technique used in this report is Multiple Linear Regression (MLR), sometimes also called Partial Least Squares (PLS) regression. I compared the PCB congener fingerprints in the samples with those in the Aroclors as measured either by Rushneck et al. (2004) on an SPB-octyl gas chromatography column or by Pacific Rim Laboratories on an SGE-HT8 gas chromatography column. This technique conducts a MLR of the congener fingerprint of the sample (y) versus the Aroclor fingerprints (x's). A multiple linear regression was performed in which a congener pattern was calculated that represented a linear combination of the five main Aroclors:

$$C_f = aC_{1016} + bC_{1242} + cC_{1248} + dC_{1254} + eC_{1260} \quad (4)$$

where

C = concentration of the resolved factor (f) or individual Aroclor,
a, b, c, d and e = partial regression coefficients.

When any of the coefficients was zero or negative, that Aroclor was removed from the regression and the MLF was rerun. This approach follows the scheme outlined by Burkhard and

Weininger (1987) and more recently by Zhang and Harrington (2015). This approach has been widely used to determine PCB sources (Swackhamer and Armstrong, 1988; Verbrugge et al., 1991). MLR was conducted using the LINEST feature of Excel and/or via python code. Congener fingerprints were normalized such as that each congener/peak was expressed as a percent of the total fingerprint, with the sum of all congeners equal to 100%. For purposes of MLR, non-detects were set to zero, because in their measurements of the fingerprints of the Aroclors performed by Rushneck et al. (2004) via method 1668 and by Frame (1997) and Frame et al. (1996), non-detects were likewise set to zero and no information about detection limits was available.

In the PCB source evaluation project in the Green-Duwamish River system in Washington State (Rodenburg and Leidos, 2017a), the Washington State Department of Ecology accepted the interpretation that when the agreement (R^2) between a fingerprint and a single Aroclor is greater than approximately 0.8, the factor was considered to represent an unweathered single Aroclor. When the agreement was between approximately 0.4 and 0.8, the fingerprint was interpreted as representing a weathered Aroclor.

Measurement of PCBs

The congener-specific PCB data evaluated here were collected using U.S. Environmental Protection Agency (EPA) Method 1668, which was first published in 1999 and has undergone several revisions since then (EPA, 1999). The first version was Method 1668A, and subsequent minor revisions are denoted as 1668B, 1668C, and 1668D. There is relatively little difference between the various revisions, and data collected under different revisions are highly comparable and can generally be pooled and used together. Method 1668 uses a high-resolution mass spectrometer (MS) coupled with high-resolution gas chromatography (GC) to measure PCBs in any matrix. Chromatography is the science of separating a mixture into its individual components by injecting the mixture into a mobile phase, which then passes through a stationary phase. Some compounds in the mixture spend more time sorbed onto the stationary phase. Because these compounds spend more time not moving, they will emerge (elute) from the chromatographic system later. The amount of time a compound takes to travel through the chromatographic system is its retention time. In GC, the mobile phase is a gas (usually helium), and the stationary phase can be any one of a number of organic compounds chemically bonded to a stationary support. There are hundreds of GC columns commercially available. The primary mechanism causing some PCB congeners to be retained longer on any of these columns is their condensation on the stationary phase; therefore, the primary chemical property that determines the retention time is the compound's vapor pressure. The type of stationary phase has a lesser, but still important, impact on the compound's retention time.

There are 209 PCB congeners. A homologue group is a set of congeners that have the same number of chlorines. The MS used in Method 1668 can discern between different masses of the PCB molecule; therefore, congeners that have the same retention time but different masses (i.e., different homologues) can be quantified separately. The key difficulty in measuring PCBs is that, within a homologue group, there are often several congeners that are so similar in their

vapor pressure that they have essentially the same retention time; therefore, they cannot be quantified separately and can only be reported as the sum of multiple congeners. One of the primary goals when developing Method 1668 was to find a column that would resolve the 12 dioxin-like PCB congeners into 12 separate peaks, each with its own unique retention time, such that none of the 12 coelute with any other PCB congener. This would allow the results to be used to calculate a toxic equivalency quotient (TEQ) by multiplying the concentration of each dioxin-like congener by its corresponding toxic equivalency factor (TEF).

Separating the 12 dioxin-like congeners from all the others is difficult. Even after much effort, Method 1668 could only separate 10 of the 12 completely, with the 2 remaining dioxin-like congeners (PCB-156 and PCB-157) coeluting with each other using an SPB-octyl column. Fortunately, PCB-156 and PCB-157 have the same TEF; therefore, the calculation of the TEQ was not affected. However, the column that had been most commonly used for PCB analysis since the 1980s could separate PCB-156 and PCB-157 into 2 separate peaks, but it could not resolve all of the other 10 dioxin-like congeners. This column is referred to as DB-1 in Method 1668, but it is also referred to as DB-5, as well as a number of other names. The authors of Method 1668 allowed this column as an alternate. As written, Method 1668 requires the use of "[a]ny GC column or column system (2 or more columns) that provides unique resolution and identification of the Toxics for determination of a TEQPCB using TEFs...Isomers may be unresolved so long as they have the same TEF and response factor and so long as these unresolved isomers are uniquely resolved from all other congeners. For example, the SPB-octyl column…achieves unique GC resolution of all Toxics except congeners with IUPAC numbers 156 and 157. This isomeric pair is uniquely resolved from all other congeners and these congeners have the same TEF and response factor…The DB-1 column is optional and is capable of uniquely resolving the congener pair with IUPAC 156 and 157" (EPA, 1999).

To complicate matters further, SGE Analytical Science produces a column called the SGE-HT8, which is capable of resolving more congeners than the DB-5 and is more rugged than the SPB-octyl. This column is often used for PCB analysis by Method 1668, especially in the Spokane area.

As noted, there is no column that can separate all 209 congeners into 209 separate peaks. Some congeners will always coelute. The problem is that the coelution patterns are very different on the SPB-octyl, SGE-HT8, and DB-5 equivalent columns. Table 1 summarizes the most common coelution patterns, but differences can be observed depending on the lot and age of the GC column. These differences are usually minor for the SPB-octyl and DB-5 columns, but the coelution patterns can vary substantially on the SGE-HT8 column.

As Table 2 demonstrates, if the goal is to mix data collected on the different types of columns into a single data set for analysis, the concentrations reported for a variety of congeners must sometimes be summed. One example is PCB-85. On the DB-5 column, six separate reported concentrations must be summed to equal the sum of three reported concentrations from the SPB-octyl column, which yields a single concentration representing the sum of PCB congeners 85, 86, 87, 97, 108, 112, 116, 117, 119, and 125. Information is lost. As a result, while the DB-5

column reports the 209 PCBs in about 168 chromatographic peaks, and the SPB-octyl column reports the 209 congeners in about 159 peaks, a data set in which SPB-octyl and DB-5 data have been combined will contain only about 128 peaks. A data set in which all three types of columns have been used will contain only about 122 peaks after they are composited. For these reasons, I avoided compositing data whenever possible.

Table 2. PCB Congener Coelution Patterns on the DB-5 (or equivalent), SGE-HT8, and SPB-octyl GC Columns. Reproduced from (Rodenburg and Leidos, 2017b).

DB-5	SGE-HT8	SPB-octyl
PCB-4+10	PCB-4	PCB-4
	PCB-10	PCB-10
PCB-5+8	PCB-5+8	PCB-5
		PCB-8
PCB-7+9	PCB-7	PCB-7
	PCB-9	PCB-9
PCB-12+13	PCB-12+13	PCB-12+13
PCB-16+32	PCB-16	PCB-16
	PCB-32	PCB-32
PCB-18	PCB-18	PCB-18+30
PCB-30	PCB-30	
PCB-20+21+33	PCB-20+33	PCB-20+28
PCB-28	PCB-21	PCB-21+33
	PCB-28	
PCB-24+27	PCB-24	PCB-24
	PCB-27	PCB-27
PCB-26	PCB-26	PCB-26+29
PCB-29	PCB-29	
PCB-40	PCB-40+57	PCB-40+41+71
PCB-41+64+71+72	PCB-41	PCB-57
PCB-57	PCB-64+72	PCB-64
	PCB-71	PCB-72
PCB-42+59	PCB-42	PCB-42
PCB-43+49	PCB-43+49	PCB-43
PCB-44	PCB-44	PCB-44+47+65
PCB-47	PCB-47+48	PCB-48
PCB-48+75	PCB-52+69	PCB-49+69
PCB-52+69	PCB-49	PCB-52
PCB-62	PCB-62	PCB-59+62+75
PCB-65	PCB-65+75	
PCB-45	PCB-45	PCB-45+51
PCB-51	PCB-51	

DB-5	SGE-HT8	SPB-octyl
PCB-50	PCB-50	PCB-50+53
PCB-53	PCB-53	
PCB-56+60	PCB-56	PCB-56
	PCB-60	PCB-60
PCB-61+70	PCB-61	PCB-61+70+74+76
PCB-66+76	PCB-66	PCB-66
PCB-74	PCB-70	
	PCB-74	
	PCB-76	
PCB-83	PCB-83+109	PCB-83+99
PCB-85+116	PCB-85	PCB-85+116+117
PCB-86	PCB-86+97+117	PCB-86+87+97+108+119+125
PCB-87+117+125	PCB-87+115	
PCB-97		
PCB-99	PCB-99	
PCB-107+109	PCB-107+108	PCB-107+124
PCB-108+112		PCB-109
PCB-110	PCB-110	PCB-110+115
PCB-111+115	PCB-111	PCB-111
PCB-119	PCB-112+119	PCB-112
	PCB-116+125	
PCB-124	PCB-124	
PCB-84+92	PCB-84	PCB-84
	PCB-92	PCB-92
PCB-88+91	PCB-88	PCB-88+91
	PCB-91	
PCB-93	PCB-93+98+102	PCB-93+95+98+100+102
PCB-95+98+102	PCB-95	
PCB-100	PCB-100	
PCB-90+101	PCB-90	PCB-90+101+113
PCB-113	PCB-101	
	PCB-113	
PCB-105	PCB-105+127	PCB-105
PCB-127		PCB-127
PCB-106+118	PCB-106	PCB-106
	PCB-118	PCB-118
PCB-128+162	PCB-128	PCB-128+166

DB-5	SGE-HT8	SPB-octyl
PCB-166	PCB-162	PCB-162
	PCB-166	
PCB-129	PCB-129	PCB-129+138+160+163
PCB-138+163+164	PCB-138	PCB-158
PCB-158+160	PCB-158	PCB-164
	PCB-160	
	PCB-163+164	
PCB-132+161	PCB-132+161	PCB-132
		PCB-161
PCB-133+142	PCB-133	PCB-133
	PCB-142	PCB-142
PCB-135	PCB-135	PCB-135+151+154
PCB-151	PCB-151	
PCB-154	PCB-154	
PCB-136	PCB-136+148	PCB-136
PCB-148		PCB-148
PCB-134+143	PCB-134	PCB-134+143
PCB-139+149	PCB-139+149	PCB -139+140
PCB-140	PCB-140	PCB-146
PCB-146+165	PCB-143	PCB-147+149
PCB-147	PCB-146	PCB-165
	PCB-147	
	PCB-165	
PCB-153	PCB-153	PCB-153+168
PCB-168	PCB-168	
PCB-156	PCB-156	PCB-156+157
PCB-157	PCB-157	
PCB-171	PCB-171	PCB-171+173
PCB-173	PCB-173	
PCB-180	PCB-180	PCB-180+193
PCB-193	PCB-193	
PCB-182+187	PCB-182+187	PCB-182
		PCB-187
PCB-183	PCB-183	PCB-183+185
PCB-185	PCB-185	
PCB-196+203	PCB-196	PCB-196
	PCB-203	PCB-203

DB-5	SGE-HT8	SPB-octyl
PCB-197	PCB-197	PCB-197+200
PCB-200	PCB-200	
PCB-198	PCB-198	PCB-198+199
PCB-199	PCB-199	

Congeners that do not coelute on any column are not shown.

GC = Gas chromatography.

PCB = Polychlorinated biphenyl.

Non-Aroclor PCB congeners

The primary focus of this analysis is to identify PCBs that arise from sources other than Aroclors (or other commercial PCB formulations). How can this be accomplished using PMF? In order for a factor that is isolated by PMF to be identified as a "non-Aroclor" source, it must fulfill three criteria. First, it should not resemble any of the Aroclors. As noted above, in the PCB source evaluation project in the Green-Duwamish River system in Washington State (Rodenburg and Leidos, 2017a), the Washington State Department of Ecology accepted the interpretation that when the agreement (R^2) between the fingerprint produced by the PMF program and a single Aroclor is greater than approximately 0.8, the factor was considered to represent an unweathered single Aroclor. When the agreement was not as good (i.e., R^2 between approximately 0.4 and 0.8), the factor was interpreted as representing a weathered Aroclor.

The second criteria is that when the agreement between the Aroclor and the factor (R^2) is less than 0.4, the differences between the Aroclor and the factor cannot be explained by any known weathering phenomenon. Weathering processes include partitioning between air, water, or sediment as well as metabolism by biota or bacteria. Often PMF generates factors from biota that are not similar to the Aroclors, but the differences conform with current knowledge about the metabolism of PCB congeners via the cytochrome P-450 pathway (Boon et al., 1997). Similarly, in anaerobic environments, bacteria are able to remove one or more of the chlorines from the PCB molecule, turning one PCB congener into another. This process is well understood, and produces a characteristic congener pattern (Bedard, 2003; Rodenburg et al., 2010a; Rodenburg et al., 2012; Rodenburg et al., 2015c).

The third criteria is that non-Aroclor source fingerprints will probably contain congeners that are known to be associated with non-Aroclor sources. For this reason, in order to identify non-Aroclor PCB sources, it is important to include PCB congeners in the PMF input data sets that are known to be associated with non-Aroclor sources.

The sources of PCBs that are not associated with commercial formulations that have been identified in environmental samples include pigments (Du et al., 2008; Rodenburg et al., 2010a; Rodenburg et al., 2010b; Rodenburg et al., 2011; Rodenburg et al., 2015c) and silicone products (Rodenburg and Leidos, 2017a). A variety of PCB congeners that occur in the Aroclors are also sometimes found in non-Aroclor sources such as pigments. For example, (Hu and Hornbuckle, 2009) using an SPB-octyl column identified 47 peaks containing 67 PCB congeners in commercial paint pigments. Note that this does not necessarily imply that all 67 congeners were present in the pigments. When congeners coelute (such as, for example, the coeluting group of PCBs 86+87+97+109+125) it is possible that only one of the congeners is actually contained in the pigment. Nevertheless, in these pigments, (Hu and Hornbuckle, 2009) found congeners such as PCB 52, which is present in all of the Aroclors tested by Rushneck et al. (2004) and is most abundant in Aroclor 1248, where it constitutes about 7.1% of the Aroclor by weight.

The congeners known to arise only from non-Aroclor sources are PCBs 11 (from pigments) and 68 (from silicone rubber). PCB 11 is virtually absent in the Aroclors, but has been shown to be produced in advertently during the synthesis of some organic pigments (King et al., 2002; Litten et al., 2002; Hu and Hornbuckle, 2009; Rodenburg et al., 2010b). As a result, PCB 11 is present in various consumer products that have printed designs on them or their packaging (Rodenburg et al., 2010b; Guo et al., 2014; Stone, 2014; Rodenburg et al., 2015b), and can be released from these products into environmental compartments including air, storm water, surface water, sediment, and fish tissue (King et al., 2002; Litten et al., 2002; Choi et al., 2008; Du et al., 2008; Du et al., 2009; Rodenburg et al., 2010b; Rodenburg et al., 2011; Praipipat et al., 2013; Rodenburg et al., 2015a; Rodenburg and Ralston, 2017). PCB 11 was included in all of the data sets analyzed in this report.

PCB 68 is also virtually absent in the Aroclors but is present in silicone rubber that used 2,4-dichlorobenzoyl peroxide as a curing agent (Perdih and Jan, 1994; Anezaki and Nakano, 2015; Herkert et al., 2018). As a result, it can be present in environmental samples as an artifact (contamination) when silicone rubber tubing is used to collect the sample (Greyell and Williston, 2018). Herkert et al. (2018) have argued that PCB 68 can be present in polyester resins which have been cured using 2,4-dichlorobenzoyl peroxide. Use of 2,4-dichlorobenzoyl peroxide is typically associated with PCBs 44+47+65 and 45+51 along with PCB 68. Unfortunately, 44+47+65 and 45+51 are also found in the Aroclors (Rushneck et al., 2004), and they can also be markers for dechlorination of Aroclor PCBs by bacteria (Bedard and May, 1996; Magar et al., 2005; Bedard et al., 2006; Bzdusek et al., 2006a; Fagervold et al., 2007; Rodenburg et al., 2010a).

Other congeners are almost always associated with non-Aroclor sources. PCBs 206, 208, and 209 can be produced during the synthesis of some organic (Hu and Hornbuckle, 2009) and inorganic pigments (Gamboa et al., 1999; Du et al., 2008; Praipipat et al., 2013; Rodenburg and Ralston, 2017). Although these three congeners are mostly absent in the five main Aroclors (1016, 1242, 1248, 1254, and 1260), comprising a maximum of 0.9% of PCBs in Aroclor 1260, they are present in some of the rare Aroclors. In Aroclor 1268, they comprise 51% of total PCBs

(Rushneck et al., 2004). PCB 209 was reportedly present in Aroclors 1270 and 1271 (Hermanson et al., 2016), although Rushneck et al. (2004) did not measure the congener fingerprints of these Aroclors. In some locations, PCB 209 is clearly associated with commercial PCB production. For example, PCB 209 was found to be the dominant congener in some samples of soil, tree bark, and house dust collected near the former Monsanto PCB manufacturing facility in Sauget, IL (Stratton and Sosebee, 1976; Gonzalez et al., 2011; Hermanson et al., 2016). In contrast, in some places, the presence of PCB 209 is clearly associated with pigments. For example, in the Delaware River, a PMF-generated factor dominated by PCBs 206, 208, and 209 comprises 61% of the PCB mass in the sediment (Praipipat et al., 2013) and we are reasonably certain that it arose primarily from a facility in Edgemoor, Delaware that manufactured titanium dioxide via a process that is known to produce PCBs (Gamboa et al., 1999).

PMF results

Surface water

Summary: About 90% of PCBs in the surface water of the Spokane River come from Aroclors. The PMF-generated factor that is dominated by PCB 11 accounts for about 10% of the PCBs in the Spokane River.

Matrix analyzed: 191 samples, 68 peaks. About 10% of the PCB mass is lost during the blank correction process (see below). These 68 peaks represent 92.4% of the PCB mass remaining after blank correction, i.e. 7.6% of the mass is lost when congeners are discarded because they were not detected in enough samples to be included in the PMF input. This data was collected by the SRRTTF during 2014-2018 and provided by the SRRTTF via multiple spreadsheets.

Blank correction: Because the concentrations of PCBs in the surface waters of the Spokane River are relatively low (around 200-400 pg/L) and the concentrations in the blanks are around 88 pg/L, blank correction of this data is important. During 2018, I conducted a study funded by the SRRTTF to determine the optimal procedures for blank correction using the surface water data from 2014-2017 because the 2018 data was not yet available (Rodenburg, 2019). This study concluded that censoring the data at one times the batch-specific blank concentration was the most appropriate method. (Censoring means designating concentrations that are less than the concentration in the blank as non-detects. The other widely used method of blank correction is subtraction, in which the mass in the blank is subtracted from the mass in the sample, and if the results is equal to or less than zero, the concentration is designated at non-detect.) This study also concluded that PCBs from non-commercial sources (specifically PCBs from pigment, peroxide-cured silicone, and uncured silicone) were responsible for about one-third of the PCBs in the blanks, with the other two-thirds coming from Aroclors. Blank correction resulted in the fingerprints of PCBs from the two types of silicone to be undetectable in the water column data. For this analysis, SRRTTF provided the data already censored at one times the blank concentration.

Detection limits: Detection limits were usually provided. For the small number of samples for which LODs were not available, they were inferred from the LODs provided for congeners with the same molecular weight.

Uncertainty matrix: Uncertainties were calculated from the provided surrogate recoveries.

Samples included: All surface water samples from the Spokane River were included in the data matrix, as well as 15 samples from Hangman Creek.

Results: The results were virtually identical to those described in the blank study report (Rodenburg, 2019), i.e. five factors were isolated with four resembling Aroclors and the one dominated by PCB 11. SurfW 2 resembled Aroclor 1016 (R2 = 0.67). SurfW 3 resembled Aroclor 1248 (R2 = 0.75). SurfW 4 resembled Aroclor 1254 (R2 = 0.92), and SurfW 5 resembled Arolcor 1260 (R2 = 0.78).

SurfW 1 was dominated by PCB 11 (79% of the fingerprint). Even when PCB 11 was removed from the correlation, the best match between this factor and an Aroclor was 1242 with an R2 value of just 0.1. Therefore this factor did not resemble any Aroclor and it presumably arises from non-commercial sources. SurfW 1 accounts for 10.1% of PCBs in this data set. The abundance of this factor varies by location as shown in figure 1.

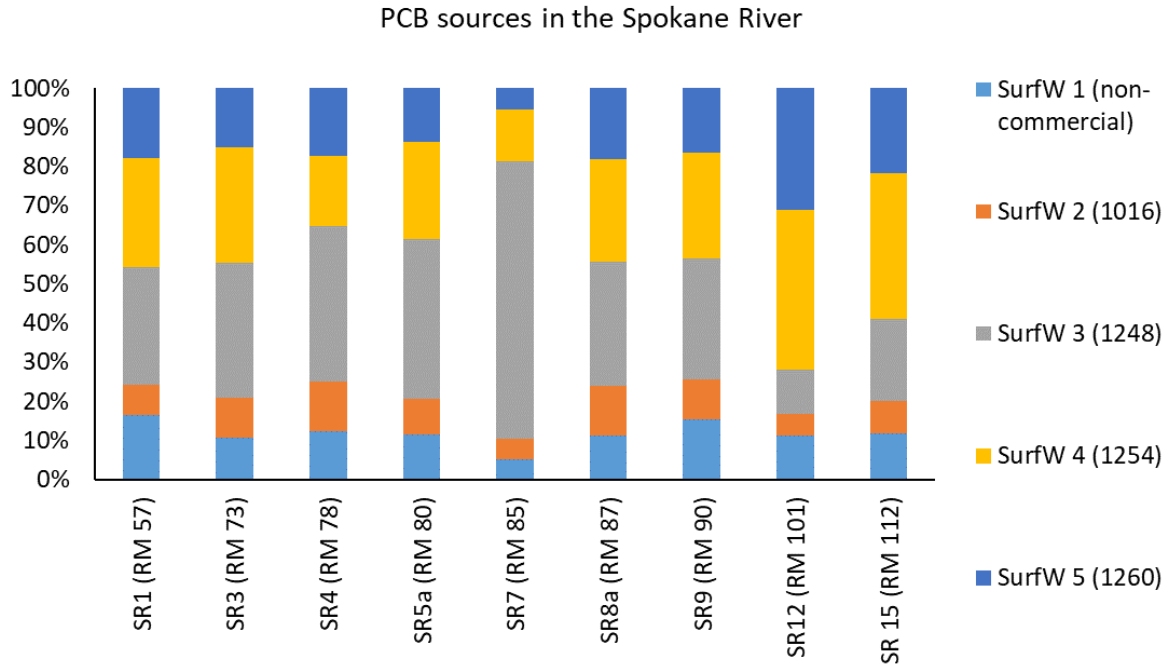

Figure 1. PCB sources to the Spokane River surface water by sampling location. River flow is from right to left, where SR15 is the outlet to Lake Coeur D'Alene and SR1 is below Nine Mile Dam. River miles (RM) are approximate.

Spokane City WWTP influent and CSO samples

Summary: More than 95% of the PCBs in the Spokane City WWTP influent and CSO samples arise from Aroclors. The PMF model generated a factor that contains some PCB 11, but this factor also resembled a mix of weathered Aroclors, suggesting that it represents a mixture of Aroclors and non-commercial PCBs. I estimate that non-commercial PCBs contribute less than 5% of the PCBs to the City wastewater influent and CSOs.

Matrix analyzed: 236 samples, 83 peaks. These peaks represent 98.6% of the PCB mass. Samples were from StudyIDs CityOfSpokaneWW (223 samples collected from 2009 to 2019), SRUW-Spokane (12 samples collected from 2009-2011), and DSER0010 (one sample from 2004). This data was provided in version 20 of the Baron and Budd database.

Samples included: Two samples from CSOs were not included in the PMF data set because they were analyzed using a DB5 column. These are analyzed separately via MLR under the section on MLR.

Blank correction: Blank correction was performed before this data was entered into the Baron and Budd v. 20 database.

Detection limits: Detection limits were usually provided. For the small number of samples for which LODs were not available, they were inferred from the LODs provided for congeners with the same molecular weight.

Uncertainty matrix: Uncertainties were calculated from the provided surrogate recoveries.

Results: The PMF analysis generated five factors. Four of the five factors resembled Aroclors. CityWW 1 strongly resembled a 50/50 mixture of Aroclors 1242 and 1248 (R2 = 0.92). CityWW 3 strongly resembled Aroclor 1254 (R2 = 0.82), CityWW 4 resembled a mixture of Aroclors 1254 and 1260 (R2 = 0.82). CityWW 5 resembled Aroclor 1254 (R2 = 0.74).

PCB 11 explained 12% of CityWW 2. The remainder of this factor resembled a mixture of Aroclors 1016, 1254, and 1260 (R2 = 0.63). This factor therefore represents a mixture of weathered Aroclors and non-commercial PCB sources. One way to interpret this R2 value is to say that Aroclor PCBs explain 63% of this fingerprint. This factor is responsible for 13% of the mass of PCBs in this data set. Since the majority of the PCBs in this factor arise from Aroclors, the fraction of PCBs in the data set that arise from non-commercial sources is less than this 13%. The minimum fraction of non-commercial PCBs in this fingerprint is 12% (the contribution from PCB 11) and the maximum is 37% (i.e. 100% minus the 63% arising from Aroclors). Thus the non-commercial contribution to the PCBs in the Spokane City wastewater influent and CSOs ranges from 1.6% (13% of mass times PCB 11's 12% of the fingerprint) to 4.8% (13% of mass times 37% the fingerprint not explained by Aroclors).

Fish tissue

Summary: PCBs in the fish of the Spokane River arise almost entirely (more than 99%) from Aroclors. The PMF model does not identify a fingerprint that is dominated by a non-commercial PCB congener.

Matrix analyzed: 105 samples, 104 peaks. These peaks represent 99.9% of the PCB mass. This data was from the following studyIDs:

- mifr0003 (4 samples collected in 2016)
- BERA0011 (10 samples collected in 2014)
- RJAC002 (15 samples collected in 2001)
- DSER0010 (15 samples collected in 2003-2004)
- WSTMP12 (36 samples collected in 2012)
- WSTMP03T (25 samples collected in 2003)

Samples included: A total of 118 samples of tissue were available. Thirteen of these were excluded from the PMF input because they were outside of the study area. Nine of these thirteen were from hatcheries.

Blank correction: Blank correction was performed before this data was entered into the Baron and Budd v. 20 database.

Detection limits: Detection limits were usually provided. For the small number of samples for which LODs were not available, they were inferred from the LODs provided for congeners with the same molecular weight.

Uncertainty matrix: Uncertainties were calculated from the provided surrogate recoveries.

Results: The PMF analysis produced six factors. Five of these six strongly resembled either a single Aroclor or a mixture of Aroclors with R2 values greater than 0.67. Fish 4 was a very weathered fingerprint. It resembles a mixture of Aroclors 1248, 1254, and 1260 (R2 = 0.46). It was dominated by PCBs 61+70+74+76, 66, 83+**99**+109, **85**+86+87+97+107+108+110+**115**+116+**117**+**119**+124+125, 105+**127**, 118, 129+**138**+160+**163**+164, **153**+**168**, and **180**+**193**. The congeners shown in bold in this list belong to groups I and II (least metabolizable) of the classification scheme devised by Boon et al. (Boon et al., 1989; Boon et al., 1997). Because these congeners are not readily metabolized by the fish, they tend to dominate in congener patterns derived from fish tissue. In our recent publication on PCB congener patterns in biota (Rodenburg and Delistraty, 2019), we noted that the ratio of 147+149 to 153+168 could be used as an indicator of the degree of metabolism of the PCB mixture. In the present data set, 147+149 was combined with 139 and 140. Therefore 139+140+147+149 represents a group of congeners that are readily metabolized, while 153+168 are not. The ratio of (139+140+147+149)/(153+168) is close to 1 in the five main Aroclors (ranging from 0.99 in Aroclor 1260 to 1.16 in Aroclor 1248). In the fish 4 factor, this ratio is 0.07, indicating extensive metabolism.

PCBs from non-commercial source are negligible in the fish tissue. PCB 11 was not detected in 48 of the 105 samples of fish. PCB 11 constituted a maximum of 0.4% of the sum of PCBs in these samples (non-detects set to zero). PCB 209 was not detected in 23 of the 105 samples. PCB 209 comprised a maximum of 0.2% of the sum of PCBs in these samples (non-detects set to zero).

Spokane Stormwater

Summary: PCBs in the stormwater arise primarily from Aroclors. The PMF analysis does not generate a factor that is dominated by non-commercial PCBs. PCBs 11 and 209 make up about 1% of total PCBs in the stormwater.

Matrix analyzed: The stormwater input matrix included 106 samples from the following studyIDs:

- CityOfSpokaneWW (41 samples collected from 2012-2016)
- SRUW-Spokane (35 samples collected from 2009-2011)
- BRWA0004 (30 samples collected in 2007)

Ninety-one PCB peaks were included in the PMF input. These peaks contained 98.2% of the PCB mass detected across all peaks/samples.

Samples included: Thirteen samples from studyID BRWA0004 were not included in the PMF input because less than 10 PCB peaks were detected in them. A further 23 samples were not included in the PMF input because they were analyzed using an SPB-octyl column. These are discussed below in the section on MLR.

Blank correction: Blank correction was performed before this data was entered into the database.

Detection limits: Detection limits were usually provided. For the small number of samples for which LODs were not available, they were inferred from the LODs provided for congeners with the same molecular weight.

Uncertainty matrix: Uncertainties were calculated from the provided surrogate recoveries.

Results: Five factors were isolated from the PMF analysis. Because most of these samples were analyzed using an SGE-HT8 column, I used the Aroclor patterns from Pacific Rim laboratories to determine whether the PMF-derived factors resembled Aroclors. StormW 1 resembled Aroclor 1242 (R2 = 0.67). StormW 2 resembled Aroclor 1254 (R2 = 0.86). StormW 5 resembled Aroclor 1260 (R2 = 0.87). StormW 4 and StormW 5 somewhat resembled Aroclors. The best-fit profiles for these two factors as a mixture of Aroclors resulted in R2 values of 0.34 for StormW 4 and 0.49 for StormW 5. PCB 11 comprised 4.3% of StormW 4 and 3.2% of StormW 5. These are not particularly high percentages. Other congeners that are sometimes associated with non-commercial PCBs sources are not very abundant in these two factors. For

example, PCB 35 is less than 0.1% of either StormW 4 or StormW 5. Similarly, PCB 209 is less than 1% of each factor. The ratio of PCBs 139+149 (readily metabolizable) to PCBs 153+168 (recalcitrant) is about 1.2 in the Aroclors, but is 0.57 in StormW 4 and is a miniscule 0.0001 in StormW 3. This indicates extensive metabolic weathering of these two factors. This might indicate the presence of feces in the stormwater, possibly from wildlife or pets. Regardless, there is little indication that these fingerprints represent non-commercial sources. More likely, they represent highly weathered Aroclors. PCB 11 comprises 0.8% of total PCBs in these stormwater samples and PCB 209 comprises 0.2% (non-detects set to zero). Thus the total contribution of non-commercial PCBs in the stormwater is about 1%.

Kaiser groundwater

Summary: PCBs in the groundwater at the Kaiser plant arise virtually exclusively from Aroclors. There is evidence of microbial dechlorination of PCBs occurring in the groundwater.

Matrix analyzed: The Kaiser groundwater input matrix included 166 samples and 70 PCB peaks. Most of this data was provided by the SRRTTF. Ten samples of groundwater collected in 2010 were obtained from the Baron and Budd database version 20. These peaks contained 99.1% of the PCB mass detected across all peaks/samples.

Samples included: Sixty-two samples were excluded because less than 30 congeners were detected in them. A further six samples marked “River @ Pump House” were not included because they represented river water, not groundwater.

Blank correction: I manually blank corrected this data by censoring at one times the batch-specific blank concentration.

Detection limits: Detection limits were usually provided. For the small number of samples for which LODs were not available, they were inferred from the LODs provided for congeners with the same molecular weight.

Uncertainty matrix: Uncertainties were calculated from the provided surrogate recoveries.

Results: The PMF program isolated four factors from the Kaiser groundwater data set. KaiserGW 3 resembled Aroclor 1248 (R2 = 0.71) and is responsible for 62% of the mass in the data set. KaiserGW 4 strongly resembled Aroclor 1254 (R2 = 0.96) and is responsible for 7% of the mass in the data set. The other two factors show evidence of microbial dechlorination of PCBs occurring in the groundwater. Some strains of anaerobic bacteria can remove chlorines from PCBs, resulting in PCB congeners with fewer chlorines (Brown et al., 1987). This process appears to occur in groundwater (Rodenburg et al., 2015c). Thus it is not surprising that it may be happening in the groundwater at the Kaiser site. KaiserGW 1 and KaiserGW2 both contain elevated levels of PCBs known to be products of dechlorination, particularly PCBs 19, 44+47+65 and 45+51. These two factors contain less than 0.1% each of PCBs 11 and 209, indicating that they are unlikely to come from non-commercial sources. PCB 68 was detected in only 35 of the

166 samples included in the PMF input. PCB 11 is about 0.01% of total PCBs in the Kaiser groundwater, and PCB 209 is about 0.001%.

Kaiser outfalls

Summary: Measurements of PCBs in the effluent from the Kaiser treatment plant appear to be impacted by a sampling artifact related to the use of silicone rubber tubing during sampling in one study. When steps are taken to account for this artifact, PCBs in the effluent arise overwhelmingly from Aroclors. Non-commercial PCBs make up about 2% of total PCBs in the Kaiser effluent.

Matrix analyzed: The Kaiser outfall input matrix included 225 samples from the following studyIDs:

- SGOL005 (two samples from 2001)
- SGOL001 (four samples from 2000)
- KaiserWWTP (142 samples from 2007-2011)
- DSER0010 (seven samples from 2003-2004)
- EffluentE120142015 (52 samples from 2014-2015)
- SRRTTF-2014 (four samples from 2014)
- SRRTTF-2015 (four samples from 2015)
- SRRTTF-2018 (ten samples from 2018)

Eighty-three PCB peaks were included in the PMF input. These peaks contained 99.1% of the PCB mass detected across all peaks/samples.

Samples included: All available samples were included in the PMF input.

Blank correction: Blank correction was performed before this data was entered into the Baron and Budd v 20 database.

Detection limits: Detection limits were usually provided. For the small number of samples for which LODs were not available, they were inferred from the LODs provided for congeners with the same molecular weight.

Uncertainty matrix: Uncertainties were calculated from the provided surrogate recoveries.

Results: Interpreting the results from the Kaiser effluents is complicated by the fact that the data appear to be impacted by a sampling artifact related to the use of silicone rubber tubing for sampling in studyID EffluentE120142015. PCB 68 is used as a marker for silicone rubber contamination because it is virtually absent in the Aroclors. In samples from studyIDs SGOL005 and SGOL001, PCB 68 is never detected. In samples from studyID KaiserWWTP, PCB 68 is detected in just eight of 134 samples included in the PMF input. In these eight samples, the maximum amount of PCB 68 is 0.15% of the sum of PCBs (non-detects set to zero). In contrast,

PCB 68 is detected in all 52 of the samples from studyID EffluentE120142015, and ranged from 0.9% to 3.6% of the sum of PCBs. PCB 68 is also detected in 14 of the 18 samples from the various SRRTTF studyIDs. These are the same studies that collected the data for the surface water analysis discussed above. As I noted in the section of surface water, blank correction of those studies is important. Blank correction of data in the Baron and Budd database was performed prior to the inclusion of the data in the database. It appears that this level of blank correction may have been insufficient to remove the influence of silicone rubber on the EffluentE120142015 samples.

PMF analysis of the full data set generated seven factors. Five of these seven could be described either as a single Aroclor or a mixture of Aroclors with R2 values ranging from 0.71 to 0.92. Kaiser outfall 4 was dominated by PCBs 4 and 19, which are characteristic end products of the microbial dechlorination of Aroclor-type PCBs (Brown et al., 1987). Therefore Kaiser outfall 4 represents an advanced stage of microbial dechlorination of PCBs, which is believed to be occurring in the groundwater at the Kaiser plant (see section on Kaiser groundwater, above).

In systems where bacteria are/were dechlorinating PCBs, it is common to see second dechlorination signal that is dominated by PCBs 44+47+65 and 47+51 (Bzdusek et al., 2006b; Rodenburg et al., 2010a), and indeed these congeners were seen in the Kaiser groundwater samples. Because these congeners have four chlorines, while PCB 4 has two and PCB 19 has three, the signal dominated by 44+47+65 and 45+51 has been called the 'partial' dechlorination factor (Rodenburg et al., 2010a). Kaiser outfall 5 may represent this partial dechlorination signal, because 44+47+65 makes up 18% of this fingerprint and 45+51 makes up 9%. However, PCB 68 is also found in this factor at 7%.

In order to determine whether Kaiser outfall 5 represents the dechlorination of Aroclor PCBs or silicone rubber contamination, I analyzed a smaller data set containing the same 83 PCB peaks and the 173 samples from all studyIDs except EffluentE120142015. This smaller data set generated seven factors. Each had a nearly perfect match in the solution from the larger data set. The R2 values for these matches were greater than 0.91 for all but Kaiser outfall 5, for which the R2 value was 0.70. One reason for the lower R2 value was that the fifth factor from this smaller data set contained very little PCB 68 (0.1%) while Kaiser outfall 5 contained 7% PCB 68. This fifth factor continues to contain high contributions from PCBs 44+47+65 and 45+51. This suggests that Kaiser outfall 5 represents a mixture of PCBs from silicone rubber and from the partial dechlorination occurring in the groundwater.

I have concluded that the PCB 68 found in the Kaiser outfall samples from studyID EffluentE120142015 was a result of contamination during sampling. Further, I conclude that the PCBs 44+47+65 and 45+51 in the outfall samples arose from the microbial dechlorination of Aroclor PCBs. I reach this conclusion based on the following lines of evidence. First, PCB 68 was only found in abundance in one of the eight studies. Other studies that collected water samples during the same years did not find significant amounts of PCB 68. Second, microbial dechlorination of PCBs is/was occurring at the site, as shown by the presence of the advanced dechlorination factor (Kaiser outfall 4). Third, when the samples from studyID

EffluentE120142015 are excluded, the PMF analysis produces a factor that contains high proportions of 44+47+65 and 45+51 but very little PCB 68. This suggests that 44+47+65 and 45+51 are important and abundant congeners in the outfall even when PCB 68 is not present and even when different sampling procedures were used. Third, other studies have demonstrated that when PCBs are being dechlorinated by bacteria, two dechlorination fingerprints are observed, one dominated by PCB 4 and 19 (as in Kaiser outfall 4) and a second that is dominated by PCB 44+47+65 and 45+51 (Rodenburg et al., 2010a; Rodenburg et al., 2012). This explains the abundance of 44+47+65 and 45+51 even in the absence of PCB 68. Fifth, 44+47+65 and 45+51 have been shown to be dechlorination products in systems where only Aroclor PCBs were present (Bedard and May, 1996; Bedard et al., 1997). Sixth, there is no indication of non-commercial PCBs in the outfalls at sufficient concentrations to serve as substrates for dechlorination that might produce PCBs 4, 19, 44+47+65 and 45+51. Seventh, structurally, PCB 68 cannot be a parent PCB that produces PCBs 4, 19, 44+47+65 and 45+51. PCB 68 has four chlorines, so removal of chlorines cannot produce 44+47+65 and 45+51 which also have four chlorines. PCBs 4 and 19 have 2 and 3 chlorines in the ortho positions respectively, while PCB 68 has only one.

PCB 11 comprises about 1.6% of total PCBs in the Kaiser outfall samples, and PCB 209 comprises about 0.4% (non-detects set to zero).

MLR results

The results of the MLR analysis are presented in table 3. The MLR was sometimes re-run with PCB 11 excluded. In those cases, the Aroclors listed are those found to be significant in the regression with PCB 11 excluded. The number of peaks included in the MLR and the number of peaks detected refer to the data set when PCB 11 was included. Samples analyzed on either an SGE-HT8 or DB5 column were regressed against the Aroclor patterns as measured by Pacific Rim Laboratories. Samples analyzed on an SPB-octyl column were regressed against the Aroclors as measured by Rushneck et al. (2004). All data from the Baron and Budd v 20 database were blank corrected before being entered into the database. All data from SRRTTF was blank corrected by SRRTTF.

Table 3. Results of the MLR analysis of individual samples

Matrix	StudyID (BB v20)	Location	Sample ID	Column	Number of peaks used	Detected peaks	R2	R2 w/o PCB 11	Aroclor(s)				PCB 11	PCB-209	Data source
CSO	BRWA0004	STMWTR_ERIECSO	7184223	DB5	101	87	0.85	0.85	1260				0.6%	0.1%	BB v 20
CSO	BRWA0004	STMWTR_ERIECSO	7234723	DB5	101	84	0.82	0.82	1260				0.5%	0.1%	BB v 20
Treated effluent	CityOfSpokaneWW	Spokane City WWTP	L2019899-2	SPB-octyl	120	108	0.71	0.85	1248	1254	1260		4.4%	0.20%	BB v 20
Treated effluent	CityOfSpokaneWW	Spokane City WWTP	L2046716-5	SPB-octyl	120	94	0.43	0.67	1254	1260			3.4%	0.12%	BB v 20
Treated effluent	CityOfSpokaneWW	Spokane City WWTP	L2046716-6	SPB-octyl	120	104	0.31	0.86	1242	1254	1260		4.7%	0.11%	BB v 20
Treated effluent	CityOfSpokaneWW	Spokane City WWTP	L2079391-4	SPB-octyl	120	86	0.76	0.76	1254	1260			0%	0.11%	BB v 20
Treated effluent	CityOfSpokaneWW	Spokane City WWTP	L2132392-2	SPB-octyl	120	86	0.78	0.89	1016	1248	1254	1260	3.5%	0.08%	BB v 20
Treated effluent	CityOfSpokaneWW	Spokane City WWTP	L2195827-2	SPB-octyl	120	97	0.62	0.71	1254	1260			3.6%	0.06%	BB v 20
Treated effluent	CityOfSpokaneWW	Spokane City WWTP	L2217966-3	SPB-octyl	120	69	0.80	0.84	1248	1254	1260		3.3%	0.11%	BB v 20
Treated effluent	CityOfSpokaneWW	Spokane City WWTP	PR161618	SGE-HT8	75	32	0.40	0.70	1248	1254	1260		14%	0.63%	BB v 20
Treated effluent	CityOfSpokaneWW	Spokane City WWTP	PR162811	SGE-HT8	75	57	0.48	0.87	1242	1248	1254	1260	10%	0%	BB v 20
Treated effluent	CityOfSpokaneWW	Spokane City WWTP	PR163344	SGE-HT8	75	23	0.38	0.69	1248	1254	1260		14%	0%	BB v 20
Treated effluent	CityOfSpokaneWW	Spokane City WWTP	PR163344D	SGE-HT8	75	33	0.55	0.76	1248	1254			12%	0%	BB v 20
Treated effluent	CityOfSpokaneWW	Spokane City WWTP	PR170819	SGE-HT8	75	44	0.59	0.77	1254	1260			10%	0.81%	BB v 20
Treated effluent	CityOfSpokaneWW	Spokane City WWTP	PR171292	SGE-HT8	75	46	0.23	0.28	1254	1260			8%	0.78%	BB v 20
Treated effluent	CityOfSpokaneWW	Spokane City WWTP	PR172157	SGE-HT8	75	17	0.15	0.15	1254				0%	0%	BB v 20
Biofilm	Biofilm	Barker Bridge (RM 90.4)	BB (1809040-03)	SPB-octyl	152	75	0.91	0.91	1242	1254	1260		0%	1.80%	SRRTTF
Tissue	Biofilm	GE Mission Left Bank caddis fly larvea	GEM-INVERT (1809040-29)	SPB-octyl	152	121	0.51	0.51	1242	1254	1260		0%	0.02%	SRRTTF
Biofilm	Biofilm	GE Mission Left Bank (RM 78.7)	GEM-LB (1809040-07)	SPB-octyl	152	123	0.90	0.92	1242	1254	1260		2.5%	0.11%	SRRTTF

Matrix	StudyID (BB v20)	Location	Sample ID	Column	Number of peaks used	Detected peaks	R2	R2 w/o PCB 11	Aroclor(s)				PCB 11	PCB-209	Data source
Biofilm	Biofilm	GE Mission Right Bank (RM 78.7)	GEM-RB (1809040-08)	SPB-octyl	152	120	0.55	0.82	1242	1248	1254	1260	8.6%	0.18%	SRRTTF
Biofilm	Biofilm	Green Street Left Bank (RM 78.0)	GR-LB (1809040-09)	SPB-octyl	152	119	0.79	0.94	1242	1248	1254	1260	6.2%	0.20%	SRRTTF
Biofilm	Biofilm	Green Street Right Bank (RM 78.0)	GR-RB (1809040-10)	SPB-octyl	152	121	0.76	0.89	1242	1248	1254	1260	6.2%	0.18%	SRRTTF
Biofilm	Biofilm	Gonzaga (RM 75.0)	GZ-BF (1809040-13)	SPB-octyl	152	129	0.90	0.93	1242	1254	1260		3.1%	0.75%	SRRTTF
Biofilm	Biofilm	Gonzaga (RM 75.0)	GZ-BF-DUP (1809040-21)	SPB-octyl	152	135	0.80	0.80	1242	1248	1254	1260	1.3%	0.06%	SRRTTF
River sediment	Biofilm	Gonzaga-Sediment (RM 75.0)	GZ-SED (1809040-23)	SPB-octyl	152	138	0.99	0.99	1242	1254	1260		0.05%	0.05%	SRRTTF
River sediment	Biofilm	Gonzaga-Sediment (RM 75.0)	GZ-SED-DUP (1809040-25)	SPB-octyl	152	136	0.98	0.98	1242	1254	1260		0.08%	0.07%	SRRTTF
Biofilm	Biofilm	Harvard Bridge (RM 92.7)	HB (1809040-02)	SPB-octyl	152	98	0.85	0.85	1242	1254	1260		0%	1.08%	SRRTTF
Biofilm	Biofilm	Hangman Creek (RM 0.8)	HM-BF (1809040-16)	SPB-octyl	152	112	0.94	0.94	1242	1248	1254	1260	0%	0.32%	SRRTTF
River sediment	Biofilm	Hangman Creek (RM 0.8)	HM-SED (1809040-22)	SPB-octyl	152	120	0.94	0.95	1242	1254	1260		0.75%	1.31%	SRRTTF
Biofilm	Biofilm	Mirabeau (RM 86.6)	MBU (1809040-04)	SPB-octyl	152	108	0.62	0.66	1248	1260			3.8%	1.56%	SRRTTF
Biofilm	Biofilm	Mission Bridge (RM 76.6)	MIB (1809040-11)	SPB-octyl	152	139	0.86	0.91	1242	1248	1254	1260	2.4%	0.25%	SRRTTF
Biofilm	Biofilm	Monroe Bridge (RM 73.8)	MOB (1809040-14)	SPB-octyl	152	118	0.90	0.94	1242	1254	1260		3.8%	0.29%	SRRTTF
Biofilm	Biofilm	Nine Mile Dam (RM 57.7)	NMD (1809040-19)	SPB-octyl	152	112	0.78	0.94	1242	1248	1254	1260	7.0%	0.32%	SRRTTF
Biofilm	Biofilm	Plantes Ferry-Biofilm (RM 84.8)	PF-BF (1809040-05)	SPB-octyl	152	117	0.92	0.92	1242	1248	1254	1260	0%	0.14%	SRRTTF
River sediment	Biofilm	Plantes Ferry-Sediment (RM 83.4)	PF-SED (1809040-24)	SPB-octyl	152	131	0.78	0.78	1242	1248	1254	1260	0.07%	0.23%	SRRTTF
Biofilm	Biofilm	Spokane Gage (RM 72.7)	SG (1809040-15)	SPB-octyl	152	125	0.97	0.98	1016	1248	1254		1.9%	0.16%	SRRTTF
Tissue	Biofilm	Spokane Gage (RM 72.7)	SG-INVERT (1809040-28)	SPB-octyl	152	140	0.88	0.88	1242	1254	1260		0.23%	0.03%	SRRTTF
Tissue	Biofilm	Spokane Gage (RM 72.7)	SG-INVERT-DUP (1809040-30)	SPB-octyl	152	137	0.88	0.88	1242	1254	1260		0.24%	0.03%	SRRTTF

Matrix	StudyID (BB v20)	Location	Sample ID	Column	Number of peaks used	Detected peaks	R2	R2 w/o PCB 11	Aroclor(s)				PCB 11	PCB-209	Data source
Biofilm	Biofilm	Stateline (RM 95.9)	SL (1809040-01)	SPB-octyl	152	83	0.90	0.90	1242	1254	1260		0%	1.84%	SRRTTF
Biofilm	Biofilm	Seven Mile Bridge (RM 62.0)	SMB (1809040-18)	SPB-octyl	152	112	0.50	0.93	1242	1248	1254	1260	13%	0.63%	SRRTTF
Biofilm	Biofilm	SR3A (RM 75.9)	SR3A (1809040-12)	SPB-octyl	152	136	0.87	0.87	1248	1260			0.06%	0.02%	SRRTTF
Biofilm	Biofilm	TJ Meenach (RM 69.9)	TJM (1809040-17)	SPB-octyl	152	97	0.79	0.88	1242	1254	1260		5.4%	0.93%	SRRTTF
Biofilm	Biofilm	Upriver Dam (RM 79.8)	URD (1809040-06)	SPB-octyl	152	122	0.39	0.82	1242	1248	1254	1260	13%	0.21%	SRRTTF
Biofilm	Biofilm	Upriver Dam (RM 79.8)	URD-DUP (1809040-20)	SPB-octyl	152	120	0.35	0.79	1242	1248	1254	1260	14%	0.21%	SRRTTF
Groundwater	GE Groundwater	GE	GE_MW01_102416	SPB-octyl	128	45	0.81		1016	1248	1254	1260	0%	0%	SRRTTF
Groundwater	GE Groundwater	GE	GE_MW10_102516	SPB-octyl	128	84	0.70		1016	1248	1254	1260	0%	0.26%	SRRTTF
Groundwater	GE Groundwater	GE	GE_MW11_102516	SPB-octyl	128	110	0.99		1260				0%	0.003%	SRRTTF
Groundwater	GE Groundwater	GE	GE_MW18_102416	SPB-octyl	128	89	0.93		1260				0%	0%	SRRTTF
Groundwater	GE Groundwater	GE	GE_MW19_102516	SPB-octyl	128	107	0.97		1260				0%	0.01%	SRRTTF
Groundwater	GE Groundwater	GE	GE_MW20_102416	SPB-octyl	128	93	0.54		1260				0%	0.02%	SRRTTF
Groundwater	GE Groundwater	GE	GE_MW21_102516	SPB-octyl	128	106	0.91		1254	1260			0%	0.03%	SRRTTF
Groundwater	GE Groundwater	GE	GE_MW22_102516	SPB-octyl	128	89	0.63		1260				0%	0%	SRRTTF
Treated industrial wastewater	IEP 2005-2017	IEP	2nd Effluent	SPB-octyl	120	83	0.78	0.94	1016	1248			8.3%	0.05%	BB v 20
Treated industrial wastewater	IEP 2005-2017	IEP	42366	SPB-octyl	120	68	0.53	0.89	1016				15%	0.05%	BB v 20
Treated industrial wastewater	IEP 2005-2017	IEP	42380	SPB-octyl	120	66	0.48	0.90	1016				17%	0%	BB v 20
Treated industrial wastewater	IEP 2005-2017	IEP	Effluent	SPB-octyl	120	94	0.57	0.94	1016	1248	1254	1260	11%	0.05%	BB v 20
Treated industrial wastewater	IEP 2005-2017	IEP	Effluent 1	SPB-octyl	120	108	0.87	0.91	1016	1248			4.1%	0.02%	BB v 20
Treated industrial wastewater	EffluentE2_2015_2016	IEP	L24531-2	SPB-octyl	120	66	0.48	0.90	1016				17%	0%	BB v 20

Matrix	StudyID (BB v20)	Location	Sample ID	Column	Number of peaks used	Detected peaks	R2	R2 w/o PCB 11	Aroclor(s)				PCB 11	PCB-209	Data source
Treated industrial wastewater	EffluentE2_2015_2016	IEP	L24531-1	SPB-octyl	120	68	0.53	0.89	1016				15%	0.05%	BB v 20
Treated industrial wastewater	SGOL005	IEP	1188181	SPB-octyl	120	70	0.47	0.98	1016	1248	1254	1260	16%	0%	BB v 20
Treated industrial wastewater	SRRTTF-2015	IEP	L24358-2	SPB-octyl	120	111	0.81	0.83	1016	1248			3.3%	0.03%	BB v 20
Treated industrial wastewater	SRRTTF-2018	IEP	L29830-3	SGE-HT8	110	100	0.53	0.77	1016				12%	0.03%	BB v 20
Treated industrial wastewater	SRRTTF-2018	IEP	L29834-12 i	SGE-HT8	110	99	0.66	0.80	1016				8.7%	0.04%	BB v 20
Treated industrial wastewater	SRRTTF-2018	IEP	L29850-5	SGE-HT8	110	87	0.72	0.85	1016				8.0%	0.04%	BB v 20
Treated industrial wastewater	SRRTTF-2018	IEP	L29884-8	SGE-HT8	110	95	0.69	0.82	1016				8.1%	0.02%	BB v 20
Treated industrial wastewater	IEP 2005-2017	IEP	Fil Effluent	SPB-octyl	154	83	0.78		1016	1248			9.1%	0.04%	BB v 20
Treated industrial wastewater	SRRTTF-2014	IEP	L21917-6 W	SPB-octyl	154	129	0.87		1016	1248			5.3%	0.02%	BB v 20
Treated industrial wastewater	IEP 2005-2017	IEP	Site 3 Week 1	SPB-octyl	154	88	0.79		1016	1248			7.0%	0%	BB v 20
Treated industrial wastewater	SRRTTF-2014	IEP	L21877-90	SPB-octyl	154	104	0.85		1016				5.2%	0.01%	BB v 20
Treated industrial wastewater	SRRTTF-2014	IEP	L21910-11	SPB-octyl	154	116	0.87		1016				5.0%	0.03%	BB v 20
Treated industrial wastewater	SRRTTF-2014	IEP	L21917-5 W	SPB-octyl	154	145	0.87		1016	1248			5.2%	0.04%	BB v 20
Treated industrial wastewater	SRRTTF-2015	IEP	L23783-24	SPB-octyl	154	121	0.90		1016	1248			4.0%	0.02%	BB v 20

Matrix	StudyID (BB v20)	Location	Sample ID	Column	Number of peaks used	Detected peaks	R2	R2 w/o PCB 11	Aroclor(s)				PCB 11	PCB-209	Data source
Treated industrial wastewater	SRRTTF-2015	IEP	L23783-42	SPB-octyl	154	109	0.86		1016	1248			5.3%	0.01%	BB v 20
Treated industrial wastewater	SRRTTF-2015	IEP	L23784-38	SPB-octyl	154	114	0.87		1016	1248			4.8%	0%	BB v 20
Treated industrial wastewater	SRRTTF-2014	IEP	L21874-7	SPB-octyl	154	114	0.85		1016	1248			4.9%	0.01%	BB v 20
Treated industrial wastewater	IEP 2005-2017	IEP	FilEff12/18/11	DB5	122	55	0.19	0.81	1016	1254			24%	0.07%	BB v 20
Treated industrial wastewater	IEP 2005-2017	IEP	IEP Fil Eff 5-13-14	DB5	122	58	0.72	0.94	1016				11%	0%	BB v 20
Treated industrial wastewater	IEP 2005-2017	IEP	IEP Fil Eff 8-27-14	DB5	122	85	0.87	0.92	1016	1248			4.5%	0%	BB v 20
Treated industrial wastewater	IEP 2005-2017	IEP	IEP Fil EffPCB	DB5	122	67	0.52	0.83	1016	1254			13%	0%	BB v 20
Treated industrial wastewater	IEP 2005-2017	IEP	Fil Effluent	DB5	122	40	0.42	0.84	1016	1254			18%	0%	BB v 20
Treated industrial wastewater	IEP 2005-2017	IEP	Fil Effluent.1	DB5	122	23	0.21	0.83	1016	1254			30%	0%	BB v 20
Treated industrial wastewater	IEP 2005-2017	IEP	Fil Effluent.2	DB5	122	46	0.18	0.87	1016	1254			28%	0%	BB v 20
Treated industrial wastewater	IEP 2005-2017	IEP	Fil Effluent.3	DB5	122	36	0.54	0.75	1016				13%	0%	BB v 20
Treated industrial wastewater	IEP 2005-2017	IEP	Fil Effluent.4	DB5	122	42	0.46	0.83	1016	1248	1254		15%	0%	BB v 20
Treated industrial wastewater	IEP 2005-2017	IEP	Fil Effluent.5	DB5	122	44	0.83	0.90	1016				6.4%	0%	BB v 20
Treated industrial wastewater	IEP 2005-2017	IEP	Fil Effluent.6	DB5	122	115	0.35	0.80	1016	1254			17%	0.05%	BB v 20

Matrix	StudyID (BB v20)	Location	Sample ID	Column	Number of peaks used	Detected peaks	R2	R2 w/o PCB 11	Aroclor(s)				PCB 11	PCB-209	Data source
Treated industrial wastewater	IEP 2005-2017	IEP	Fil Effluent.7	DB5	122	92	0.75	0.92	1016	1248			8.6%	0%	BB v 20
Treated industrial wastewater	IEP 2005-2017	IEP	Fil Effluent.8	DB5	122	110	0.91	0.92	1016	1248			1.8%	0%	BB v 20
Treated industrial wastewater	IEP 2005-2017	IEP	Fil Effluent.9	DB5	122	54	0.72	0.92	1016				11%	0%	BB v 20
Treated industrial wastewater	IEP NPDES Testing	IEP	1400356-01	DB5	122	58	0.72	0.94	1016				11%	0%	BB v 20
Treated industrial wastewater	IEP NPDES Testing	IEP	1400637-01	DB5	122	85	0.87	0.92	1016	1248			4.5%	0%	BB v 20
Treated industrial wastewater	IEP 2005-2017	IEP	Secondary Clarifier Effluent	DB5	122	22	NS	0.79	1016	1248			42%	0%	BB v 20
Atmospheric deposition	BERA0013	Augusta_AIR	1705077-5	SPB-octyl	148	66	0.69	0.68	1254	1260			0%	0%	SRRTTF
Atmospheric deposition	BERA0013	Augusta_AIR	1608070-5	SPB-octyl	148	110	0.12	0.90	1242	1248	1254	1260	15%	0.14%	SRRTTF
Atmospheric deposition	BERA0013	Augusta_AIR	1611056-4	SPB-octyl	148	115	0.90	0.90	1242	1254	1260		1.4%	0.11%	SRRTTF
Atmospheric deposition	BERA0013	Augusta_AIR	1611056-5	SPB-octyl	148	102	0.89	0.91	1242	1254	1260		1.9%	0.15%	SRRTTF
Atmospheric deposition	BERA0013	Augusta_AIR	1611056-5.1	SPB-octyl	148	102	0.89	0.91	1242	1254	1260		2.2%	0.09%	SRRTTF
Atmospheric deposition	BERA0013	Augusta_AIR	1709040-2	SPB-octyl	148	147	0.63	0.86	1016	1254			9.8%	0.01%	SRRTTF
Atmospheric deposition	BERA0013	Augusta_AIR	1709040-3	SPB-octyl	148	143	0.67	0.89	1016	1248	1254		9.4%	0.01%	SRRTTF
Atmospheric deposition	BERA0013	Augusta_AIR	1709040-4	SPB-octyl	148	142	0.62	0.81	1016	1248	1254		8.5%	0.01%	SRRTTF
Atmospheric deposition	BERA0013	Augusta_AIR	1702021-1	SPB-octyl	148	97	0.74	0.89	1242	1254	1260		6.4%	0.13%	SRRTTF
Atmospheric deposition	BERA0013	Monroe_AIR	1705077-2	SPB-octyl	148	44	0.11	0.21	1242	1254			21%	0%	SRRTTF
Atmospheric deposition	BERA0013	Monroe_AIR	1608070-2	SPB-octyl	148	101	NS	0.59	1242	1254			26%	0.13%	SRRTTF
Atmospheric deposition	BERA0013	Monroe_AIR	1608070-3	SPB-octyl	148	97	0.40	0.45	1242	1254	1260		6.3%	0.19%	SRRTTF

Matrix	StudyID (BB v20)	Location	Sample ID	Column	Number of peaks used	Detected peaks	R2	R2 w/o PCB 11	Aroclor(s)				PCB 11	PCB-209	Data source
Atmospheric deposition	BERA0013	Monroe_AIR	1608070-3.1	SPB-octyl	148	100	0.40	0.44	1242	1254	1260		6.1%	0.19%	SRRTTF
Atmospheric deposition	BERA0013	Monroe_AIR	1611056-2	SPB-octyl	148	68	0.30	0.33	1242	1254			6.6%	0%	SRRTTF
Atmospheric deposition	BERA0013	Monroe_AIR	1702021-2	SPB-octyl	148	96	0.57	0.74	1242	1254	1260		7.8%	0.12%	SRRTTF
Atmospheric deposition	BERA0013	Turnbull	1705077-4	SPB-octyl	148	2	NS	NS					0%	0%	SRRTTF
Atmospheric deposition	BERA0013	Turnbull	1705077-4.1	SPB-octyl	148	1	NS	NS					0%	0%	SRRTTF
Atmospheric deposition	BERA0013	Turnbull	1608070-4	SPB-octyl	148	50	0.17	0.25	1242	1254			17%	0.21%	SRRTTF
Atmospheric deposition	BERA0013	Turnbull	1611056-3	SPB-octyl	148	32	0.14	0.16	1242	1254			12%	0%	SRRTTF
Atmospheric deposition	BERA0013	Turnbull	1702021-3	SPB-octyl	148	88	NS	0.72	1242	1254	1260		27%	0.53%	SRRTTF
Atmospheric deposition	BERA0013	Turnbull	1702021-5	SPB-octyl	148	69	NS	0.78	1242	1254	1260		46%	0.12%	SRRTTF
Storm drain solids	SRUWSpokane	Stormwater manhole Hogan and Front	1207107-02	SPB-octyl	149	141	0.89		1242	1254	1260		0.25%	0.11%	SRRTTF
Storm drain solids	SRUWSpokane	Pacific Steel and Recycling swale	1206085-01	SPB-octyl	149	144	0.96		1016	1248	1254	1260	0.05%	0.03%	SRRTTF
River sediment	SRUWSpokane	Spokane River near Avista	1308073-12	SGE-HT8	177	110	0.82		1242	1254	1260		0.25%	0.25%	SRRTTF
Storm drain solids	SRUWSpokane	Curb Sample on Trent	1210073-03	SGE-HT8	177	147	0.96		1248	1254	1260		0.11%	0.11%	SRRTTF
Storm drain solids	SRUWSpokane	Fiske and Trent 1379308IN	1211041-01	SGE-HT8	177	147	0.87		1254	1260			0.40%	0.09%	SRRTTF
River sediment	SRUWSpokane	Spokane River near Iron Bridge	1308073-03	SGE-HT8	177	125	0.78		1242	1248	1254	1260	0.60%	0.20%	SRRTTF
River sediment	SRUWSpokane	Spokane River near Iron Bridge	1308073-03REX	SGE-HT8	177	89	0.86		1242	1248	1254	1260	0.53%	0.09%	SRRTTF
Storm drain solids	SRUWSpokane	Island Curb at Regal and Trent	1210073-02	SGE-HT8	177	148	0.96		1248	1260			0.33%	0.06%	SRRTTF
River sediment	SRUWSpokane	Spokane River near Hamilton	1308073-13	SGE-HT8	177	136	0.88		1242	1248	1254	1260	0.15%	0.10%	SRRTTF
Storm drain solids	SRUWSpokane	Regal East Curb	1210073-01	SGE-HT8	177	151	0.96		1248	1260			0.53%	0.11%	SRRTTF
River sediment	SRUWSpokane	Spokane River near Stone St	1308073-05	SGE-HT8	177	141	0.72		1242	1248	1260		0.31%	0.31%	SRRTTF

Matrix	StudyID (BB v20)	Location	Sample ID	Column	Number of peaks used	Detected peaks	R2	R2 w/o PCB 11	Aroclor(s)				PCB 11	PCB-209	Data source
River sediment	SRUWSpokane	Spokane River near Centennial Trail	1308073-04	SGE-HT8	177	142	0.76		1242	1248	1254	1260	0.24%	0.14%	SRRTTF
River sediment	SRUWSpokane	Spokane River dwnstrm of Upriver Dam	1308073-02	SGE-HT8	177	108	0.70		1242	1248	1260		0.94%	0.06%	SRRTTF
River sediment	SRUWSpokane	Spokane River downstream of Upriver Dam	1308073-01	SGE-HT8	177	108	0.65		1242	1248	1254	1260	1.4%	0.11%	SRRTTF
River sediment	SRUWSpokane	Spokane River downstream of Upriver Dam	1308073-01REX	SGE-HT8	177	71	0.77		1242	1248	1254	1260	1.8%	0.35%	SRRTTF
River sediment	SRUWSpokane	Spokane River downstream of Upriver Dam	1308073-06	SGE-HT8	177	111	0.67		1242	1248	1260		0.87%	0.07%	SRRTTF
River sediment	SRUWSpokane	Spokane River downstream of Upriver Dam	1308073-06REX	SGE-HT8	177	76	0.90		1242	1248	1254		1.0%	0.002%	SRRTTF
River sediment	SRUWSpokane	Spokane River dwnstrm S of Upriver Dam	1308073-10	SGE-HT8	177	74	0.73		1242	1248	1260		1.5%	0%	SRRTTF
Stormwater	CityOfSpokaneWW	Cochran Basin	L2019899-5	SPB-octyl	149	115	0.89	0.93	1248	1254	1260		3.3%	0.38%	BB v 20
Stormwater	CityOfSpokaneWW	Cochran Basin	L2021980-3	SPB-octyl	149	146	0.93	0.94	1016	1248	1254	1260	1.6%	0.32%	BB v 20
Stormwater	CityOfSpokaneWW	Cochran Basin	L2073458-1	SPB-octyl	149	101	0.75	0.95	1016	1248	1254	1260	7.7%	0.52%	BB v 20
Stormwater	CityOfSpokaneWW	Cochran Basin	L2073458-2	SPB-octyl	149	86	0.46	0.65	1254	1260			10%	0.60%	BB v 20
Stormwater	CityOfSpokaneWW	Cochran Basin	L2193583-3	SPB-octyl	149	133	0.92	0.93	1248	1254	1260		2.2%	0.32%	BB v 20
Stormwater	CityOfSpokaneWW	Cochran Basin	L2208880-1	SPB-octyl	149	131	0.89	0.95	1016	1248	1254	1260	3.9%	0.40%	BB v 20
Stormwater	CityOfSpokaneWW	Cochran Basin	L2230025-1	SPB-octyl	149	136	0.89	0.93	1016	1248	1254	1260	3.1%	0.33%	BB v 20
Stormwater	CityOfSpokaneWW	Cochran Basin	L2230025-2	SPB-octyl	149	136	0.89	0.92	1016	1248	1254	1260	3.0%	0.39%	BB v 20
Stormwater	SRUW-Spokane	G1-7	1211029-03	SPB-octyl	149	115	0.96	0.96	1248	1254	1260		0%	0.11%	BB v 20
Stormwater	SRUW-Spokane	G1-7	1211029-04	SPB-octyl	149	127	0.91	0.91	1248	1260			0.17%	1.0%	BB v 20
Stormwater	SRUW-Spokane	Hogan	1305055-01	SPB-octyl	149	122	0.97	0.97	1254	1260			1.1%	0.15%	BB v 20
Stormwater	SRUW-Spokane	Hogan	1305055-02	SPB-octyl	149	110	0.95	0.95	1254	1260			1.2%	0.17%	BB v 20
Stormwater	SRUW-Spokane	HoganF	1211029-02	SPB-octyl	149	105	0.81	0.81	1254	1260			0%	0.08%	BB v 20

Matrix	StudyID (BB v20)	Location	Sample ID	Column	Number of peaks used	Detected peaks	R2	R2 w/o PCB 11	Aroclor(s)				PCB 11	PCB-209	Data source
Stormwater	SRUW-Spokane	PacSteel	1206085-02	SPB-octyl	149	143	0.96	0.96	1016	1248	1254	1260	0.20%	0.04%	BB v 20
Stormwater	ABOR0001	Ralph	01-03142017	SPB-octyl	149	100	0.93	0.93	1248	1254	1260		0%	0.61%	BB v 20
Stormwater	ABOR0001	Ralph	01-03142017.1	SPB-octyl	149	105	0.93	0.93	1248	1254	1260		0%	0.61%	BB v 20
Stormwater	SRUW-Spokane	Spg-Alta	1211047-01	SPB-octyl	149	137	0.96	0.96	1254	1260			1.2%	0.11%	BB v 20
Stormwater	DSER0010	STMMISSBR	4254001	SPB-octyl	149	56	0.93	0.93	1254	1260			0%	0.41%	BB v 20
Stormwater	DSER0010	STMSUPOUT	4254003	SPB-octyl	149	22	0.90	0.90	1248	1254	1260		0%	0%	BB v 20
Stormwater	DSER0010	STMWASHBR	4254002	SPB-octyl	149	46	0.94	0.94	1248	1254	1260		0%	0%	BB v 20
Stormwater	SRUW-Spokane	Trent G1-6a	1203081-02	SPB-octyl	149	130	0.96	0.96	1248	1260			0.60%	0.07%	BB v 20
Stormwater	SRUW-Spokane	Trent G1-6b	1203081-05	SPB-octyl	149	131	0.97	0.97	1248	1254	1260		0.28%	0.08%	BB v 20
Stormwater	SRUW-Spokane	Trent@Hogan	1304046-01	SPB-octyl	149	132	0.95	0.96	1248	1254	1260		1.5%	0.18%	BB v 20
River sediment	WHOB003	Union Gospel Mission Dock	1702027-26	SPB-octyl	149	133	0.95		1242	1248	1254	1260	0.86%	0.37%	SRRTTF
River sediment	WHOB003	Union Gospel Mission Dock	1702027-27	SPB-octyl	149	135	0.85		1242	1248	1254	1260	0.75%	0.43%	SRRTTF
River sediment	WHOB003	Union Gospel Mission Dock	1606035-20	SPB-octyl	149	137	0.96		1242	1248	1254	1260	0%	0.31%	SRRTTF
River sediment	WHOB003	Union Gospel Mission Dock	1606035-21	SPB-octyl	149	135	0.96		1242	1248	1254	1260	0%	0.28%	SRRTTF
River sediment	DSER0010	BUFFALO REF	3458103-S	SPB-octyl	101	24	0.64		1254	1260			0%	5.5%	SRRTTF
River sediment	DSER0010	Harvard	3438100	SPB-octyl	101	34	0.82		1254	1260			0%	0%	SRRTTF
River sediment	DSER0010	LitlSpokSed	3504060	SPB-octyl	101	19	0.23		1260				0%	0%	SRRTTF
River sediment	DSER0010	Littlefls	3454113	SPB-octyl	101	21	0.48		1254	1260			0%	0%	SRRTTF
River sediment	DSER0010	LongLkLow	3454112	SPB-octyl	101	77	0.85		1242	1248	1254	1260	0%	0.29%	SRRTTF
River sediment	DSER0010	LongLkLow	3454114	SPB-octyl	101	74	0.83		1242	1248	1254	1260	0%	0.28%	SRRTTF
River sediment	DSER0010	LongLkMid	3454111	SPB-octyl	101	74	0.85		1242	1248	1254	1260	0%	0.32%	SRRTTF
River sediment	DSER0010	LongLkUp	4208147	SPB-octyl	101	98	0.89		1242	1248	1254	1260	0%	0.24%	SRRTTF
River sediment	DSER0010	MonroeSed	4168149	SPB-octyl	101	59	0.82		1254	1260			0%	0%	SRRTTF

Matrix	StudyID (BB v20)	Location	Sample ID	Column	Number of peaks used	Detected peaks	R2	R2 w/o PCB 11	Aroclor(s)				PCB 11	PCB-209	Data source
River sediment	DSER0010	NINEM SPM	3454105	SPB-octyl	101	82	0.93		1242	1254	1260		0%	0.22%	SRRTTF
River sediment	DSER0010	PLANTEFRY	3448100	SPB-octyl	101	40	0.72		1254	1260			0%	0%	SRRTTF
River sediment	DSER0010	SPOK-1	3458100-S	SPB-octyl	101	53	0.74		1242	1248	1254	1260	0%	0%	SRRTTF
River sediment	BERA0009	9MD-SEDT	1304017-01	SGE-HT8	174	109	0.89		1242	1248	1254	1260	0.97%	0.37%	SRRTTF
River sediment	BERA0009	9MD-SEDT	1304017-04	SGE-HT8	174	105	0.87		1242	1248	1254	1260	1.1%	0.25%	SRRTTF
River sediment	BERA0009	9MD-SEDT	1306061-01	SGE-HT8	174	99	0.85		1242	1248	1254	1260	0%	0.25%	SRRTTF
River sediment	BERA0009	UPRD-SEDT	1304017-02	SGE-HT8	174	112	0.85		1242	1248	1254	1260	0.77%	0.14%	SRRTTF
River sediment	BERA0009	UPRD-SEDT	1304017-03	SGE-HT8	174	108	0.83		1242	1248	1254	1260	1.2%	0.11%	SRRTTF
River sediment	BERA0012	LFP SedTraps	1606061-1	SPB-octyl	148	134	0.95		1242	1248	1254	1260	0.53%	0.36%	SRRTTF
River sediment	BERA0012	LFP SedTraps	1606061-2	SPB-octyl	148	139	0.94		1242	1248	1254	1260	0.98%	0.42%	SRRTTF
River sediment	BERA0012	LFP SedTraps	1606061-3	SPB-octyl	148	144	0.93		1242	1248	1254	1260	0.57%	0.28%	SRRTTF
River sediment	BERA0012	LFP SedTraps	1606061-4	SPB-octyl	148	144	0.94		1242	1248	1254	1260	0.54%	0.31%	SRRTTF
River sediment	BERA0012	LFP SedTraps	1606061-5	SPB-octyl	148	141	0.94		1242	1248	1254	1260	0.58%	0.33%	SRRTTF
River sediment	BERA0012	UGM	1602016-13	SPB-octyl	148	30	0.08		1260				0%	0%	SRRTTF
River sediment	BERA0012	UGM	1602016-14	SPB-octyl	148	29	NS						0%	0%	SRRTTF
CLAM*		Nine Mile Dam	1210040-23	SGE-HT8	126	98	0.14	0.71	1248	1254	1260		0%	0.20%	SRRTTF
CLAM*		Nine Mile Dam	1210040-24	SGE-HT8	126	98	0.27	0.78	1248	1254	1260		0%	0.27%	SRRTTF
CLAM*		Nine Mile Dam	1210040-25	SGE-HT8	126	96	0.55	0.79	1248	1254	1260		0%	0%	SRRTTF
CLAM*		Nine Mile Dam	1210040-27	SGE-HT8	126	117	0.75	0.77	1248	1254	1260		0%	0.49%	SRRTTF
CLAM*		Upriver Dam	1210040-28	SGE-HT8	126	89	0.79	0.83	1016	1248	1254		0%	0%	SRRTTF
CLAM*		Upriver Dam	1210040-29	SGE-HT8	126	86	0.79	0.81	1016	1248			0%	0%	SRRTTF
CLAM*		Upriver Dam	1210040-30	SGE-HT8	126	97	0.70	0.79	1016	1248			0%	0%	SRRTTF

Matrix	StudyID (BB v20)	Location	Sample ID	Column	Number of peaks used	Detected peaks	R2	R2 w/o PCB 11	Aroclor(s)				PCB 11	PCB-209	Data source
Storm drain solids	SRUW-Spokane	HoganF	1207107-02	SPB-octyl	159	142	0.89		1242	1254	1260		0.25%	0.11%	BB v20
Storm drain solids	SRUW-Spokane	PacSteel	1206085-01	SPB-octyl	159	145	0.96		1016	1248	1254	1260	0.05%	0.03%	BB v20
Storm drain solids	DOST0001	UNIONLPT	1202023-01	SPB-octyl	159	147	0.97		1248	1254	1260		0.80%	0.12%	BB v20
Storm drain solids	DOST0001	UNIONLPT	1203042-01	SPB-octyl	159	147	0.96		1248	1254	1260		0.85%	0.14%	BB v20
Storm drain solids	SRUW-Spokane	Curb Davis	1210073-03	SGE-HT8	151	145	0.96		1248	1254	1260		0.11%	0.11%	BB v20
Storm drain solids	SRUW-Spokane	Fiske Trent	1211041-01	SGE-HT8	151	145	0.87		1254	1260			0.40%	0.09%	BB v20
Storm drain solids	SRUW-Spokane	Island West	1210073-02	SGE-HT8	151	146	0.96		1248	1260			0.33%	0.06%	BB v20
Storm drain solids	SRUW-Spokane	Regal East	1210073-01	SGE-HT8	151	149	0.96		1248	1260			0.53%	0.11%	BB v20

NS = not significant

* = “R2 w/o PCB 11” for these samples is the R2 when PCB 7 is excluded. PCB 11 was not detected in these samples.

CSOs

As noted above, most of the City of Spokane CSO samples were analyzed using PMF and the results are described in the section on PMF. Two samples were measured using a different (DB5) GC column from studyID BRWA0004, so these two were analyzed via MLR. PCBs in these two samples arise almost exclusively from Aroclors. These two samples were strongly similar to Aroclor 1260. PCBs 11 and 209 were much less than 1% of the sum of PCBs in these samples.

Stormwater

As described above, most of the City of Spokane stormwater samples were examined using PMF. Twenty-three samples were excluded from the PMF analysis because they were analyzed on an SPB-octyl column. These samples were from studyIDs CityOfSpokaneWW (8 samples), SRUW-Spokane (10), ABOR0001 (2), and DSER0010 (3). The MLR results for these samples suggest that more than 95% of PCBs in these samples arise from Aroclors. Only one sample gives an R2 values less than 0.75 when PCB 11 is included in the correlation. The R2 for this sample (L2073458-2 from the Cochran Basin) is 0.46 and increases to 0.65 when PCB 11 is excluded from the correlation. This sample contains the most PCB 11 (10%) among the 23 samples. In the remaining samples, PCB 11 ranged from non-detect to 7.7% and averaged 1.8%.

Storm drain solids

More than 95% of PCBs in storm drain solids collected in the study area come from Aroclors. Eight samples of storm drain solids were collected under two studies (SRUW-Spokane, and DOST0001) (Lubliner, 2012). The MLR results indicate that all eight samples strongly resemble Aroclors, with R2 values ranging from 0.87 to 0.97. PCB 11 is less than 1% of the sum of PCBs in most samples. PCB 209 is less than 1% of the sum of PCBs in all eight samples.

City of Spokane Treated Effluent

Aroclors account for more than 90% of PCBs in the treated effluent of the Spokane City WWTP. When PCB 11 is excluded from the correlation, these samples (from studyID CityOfSpokaneWW) generally show strong similarity with mixtures of Aroclors. In samples where the R2 value of the MLR is low, very few congeners were detected. For example, in sample ID PR172157, the R2 value is just 0.15 because only 17 congeners were detected in this sample. This does not indicate non-commercial PCB sources, since PCBs 11 and 209 were not detected in this sample. The contribution of PCB 11 to these samples ranged from non-detect to 14% of the sum of PCBs. The average contribution of PCB 11 is 6.5%. PCB 209 is less than 1% of PCBs in all of these samples.

Bulk atmospheric deposition

Aroclors are the dominant sources of PCBs in the bulk atmospheric deposition samples. PCB 11 ranged from non-detect to 46% of the PCBs in the atmospheric deposition samples. The mass-weighted average of PCB 11 across the bulk deposition samples is 8.5%. As is common across these data sets, the R2 value for the MLR increases as more congeners are detected. This is

symptomatic of the difficulty of conducting fingerprinting in data sets with low concentrations that lead to large numbers of non-detect values. In this case, it also seems indicative of blank contamination that is most problematic for samples with low concentrations/fluxes. Once the flux rises above 2 ng/m^2/d, the R2 for the MLR is always above 0.74.

The congeners that were most abundant in the *blanks* for this study were (in order of abundance) PCBs 11, 8, 20/28, 4, 1, 31, 44/47/65, 3, 9, 18/30, 15, 21/33, and 2. All of these congeners were detected in silicone products by Anezaki and Nakano (2015). These congeners are also abundant in the samples with the lowest fluxes even after blank correction. This may indicate that the blank correction procedure for this study was inadequate. Contamination by silicone products was thought to be a problem in the atmospheric deposition study in the Green-Duwamish River, which used similar methods (Rodenburg et al., 2019).

Biofilm

Aroclors account for more than 90% of PCBs in the biofilm samples. The biofilm samples were collected in order to characterize the surface water dissolved-phase PCB concentrations, since biofilm acts as a passive sampler of the water column (Wong and Era-Miller, 2019). Therefore the predominance of Aroclor PCBs in the biofilm suggests that Aroclor PCBs also dominated in the water column. Non-commercial PCBs were found in biofilm samples. PCB 11 ranged from non-detect to 14% of the sum of PCBs, and averaged 4.4%. This is in reasonable agreement with the approximately 10% of the surface water PCBs that were found to be associated with non-commercial PCBs in the surface water PMF results above. PCB 209 was less than 2% of the sum of PCBs in all biofilm samples.

The biofilm study also collected three samples of organism tissue (caddis and mayfly larvae) (Wong and Era-Miller, 2019). PCB congener profiles in two of these samples were very similar to the Aroclors (R2 = 0.88). The third sample yielded a lower R2 value of 0.51 but this was not due to the presence of PCB 11 (which was not detected in this sample) or other non-commercial PCBs. Instead, the low R2 may be due to metabolism of PCBs. In all other biofilm samples, the ratio of 147+149/153+168 (used as an indicator of metabolism) ranged from 0.61 to 1.18, but in sample GEM-INVERT (1809040-29) the ratio was just 0.20.

The biofilm project also collected four samples of river sediment. These are discussed in the section on river sediment below.

River sediment

More than 95% of PCBs in river sediment samples arise from Aroclors. Samples of river sediment were collected in several studies:

- The biofilm study analyzed four samples of river sediment using a SPB-octyl column.
- SRUWSpokane analyzed thirteen samples of river sediment using an SGE-HT8 column.
- WHOB003 analyzed four samples of river sediment using an SPB-octyl column.
- DSER0010 analyzed twelve samples of river sediment using an SPB-octyl column.
- BERA0009 analyzed five samples of river sediment using an SPB-octyl column.

- BERA0012 analyzed seven samples of river sediment using an SPB-octyl column.

Whenever more than 30 peaks were detected, congener patterns in these sediment samples resembled Aroclors with R2 values greater than 0.72. PCB 11 was never more than 1.2% of the sum of PCBs in these samples, and PCB 209 was usually much less than 1%, although it was 5.5% of the sum of PCBs in sample 3458103-S. This sample had only 24 peaks detected.

GE groundwater

Eight samples of groundwater from the GE site indicate that Aroclors are the sole source of PCBs to these samples, with Aroclor 1260 predominant. PCB 11 was not detected in these samples, and PCB 209 was always less than 0.5% of the sum of PCBs. The presence of PCB 209 can be explained by Aroclor 1260 since this formulation contains some PCB 209 (Rushneck et al., 2004). Samples GE_MW01_102416 and GE_MW10_102516 had relatively high proportions of PCBs 44+47+65 (10% and 5% of the sum of PCBs respectively). Given the near absence of PCB 68 in these samples, the presence of PCBs 44+47+65 probably indicates that microbial dechlorination of PCBs is occurring to a limited extent in the groundwater at the GE site.

Inland Empire Paper (EIP)

Forty samples from the EIP facility, most of which represent treated effluent, indicate that the main source of PCBs to their facility is Aroclors, particularly Aroclor 1016 (with 1242 being very similar in fingerprint and probably present). This is to be expected given that Aroclor 1242 was used in carbonless copy paper (Agency for Toxic Substances and Disease Registry (ATSDR), 2000). PCB 11 is often present in high proportions in the IEP facility, ranging from 1.8% to 42% of the sum of PCBs. The highest proportion of PCB 11 was found in a sample from their secondary clarifier, i.e. water that had not undergone the full treatment process. The average contribution of PCB 11 was 11% across all samples analyzed by MLR. Again, high contributions from PCB 11 were expected since PCB 11 is found in inks used in paper (Rodenburg et al., 2010b). MLR was not performed on three samples of effluent from the IEP site from study DSER0010. In two of these samples, no PCBs were detected. In the third sample, only three congeners were detected: PCBs 1, 2, and 11.

Surface water CLAM samples

The CLAM (Continuous low-level aquatic monitoring) sampling system was used to collect seven samples representing surface water at Nine Mile Dam and Upriver Dam. MLR conducted on these samples suggests that Aroclors are the main source of PCBs in the surface water. Three of the four samples from Nine Mile Dam had high contributions of PCB 7 ranging from 5% to 20% of the sum of PCBs. In all other CLAM samples, PCB 7 was less than 4% of the sum of PCBs. PCB 7 comprised 9.4% of the mass-weighted average total PCBs. I have never before in my professional experience encountered such high proportions of PCB 7. When this congener is included in the MLR, the R2 values for these three samples are relatively low, ranging from 0.14 to 0.55. When this congener is excluded, the R2 values for all of the CLAM samples range from 0.71 to 0.83, suggesting that Aroclors are the dominant source of PCBs in these samples. These

are the R2 values shown in table 3 under "R2 w/o PCB 11". PCB 11 was not detected in any of these samples. PCB 209 was detected in three of the seven samples and comprised 0.2% of the mass-weighted average sum of PCBs.

Municipal products study

The City of Spokane conducted a study in which PCBs were measured in a variety of consumer products (City of Spokane Wastewater Management Department, 2015). My analysis of this data (Table 4) indicates that the PCBs detected in many of these products probably arose from Aroclors. It is therefore not appropriate to assume that all PCBs in consumer products arise from non-commercial (i.e., non-Aroclor) sources.

The highest R2 values for the MLR were found for short liner (used to repair pipes without having to replace them) (R2 = 0.86), crack sealer (0.86), lignosulfonate dust suppressant (0.75), road salt (0.68 and 0.64), sand for road traction (0.65), and CIPP (cured in place piping) (0.64). Several other products returned R2 values above 0.4, including hydroseed, salt brine solution, hydrostraw (undyed), deicer, antifreeze, yellow road tape, synthetic motor oil, class B Fire Fighting Foam, and calcium chloride deicer. These products may have passively absorbed Aroclor PCBs from the atmosphere, could be the result of recycled PCB-containing equipment, or been exposed to Aroclor PCBs via contact with contaminated equipment, oil, etc. The U. S. Environmental Protection Agency (2018) states that "The mismanagement of used oil contaminated with PCBs is a recurring issue faced by EPA and states, commercial and municipal used oil collection centers, and recyclers. Used oil transporters pick up oil from a variety of facilities, often without knowing the PCB concentration." Some fractions of used oil can be used in the making of asphalt (Arnold, 2017) which may explain the presence of Aroclors in the crack sealer.

My results are in agreement with those of the authors of the consumer products study, who noted the similarity of congener patterns between Aroclors and products such as thermoplastic tape, lignosulfonate, crack sealer, hydroseed, and short liner. The authors noted that the crack sealer congener pattern was most similar to Aroclor 1242, and that "Aroclor 1242 had a wide variety of end uses, one of them being in rubbers. One of the ingredients in the crack sealer is vulcanized rubber compound" (City of Spokane Wastewater Management Department, 2015).

Table 4. Results of MLR analysis of municipal products measured in consumer products by the City of Spokane (City of Spokane Wastewater Management Department, 2015).

Product	Sample ID	R2	Aroclor(s)	PCB 11	PCB 209
Short Liner	031-100314-1330	0.86	1242 1254	1.0%	0%
Crack Sealer	026-100214-1450	0.86	1242 1254	4.1%	0%
Lignosulfonate (dust sup.)	022-092914-124	0.75	1242 1254 1260	0%	0%
COS Road Salt FIELD DUP	Replicate #4	0.68	1242 1248 1254 1260	6.0%	0%

Product	Sample ID	R2	Aroclor(s)	PCB 11	PCB 209
Sand (Road Traction) LAB DUP	P312-021616-1430 DUP	0.65	1248 1260	0%	0%
Sand (Road Traction)	P312-021616-1430	0.65	1242 1248 1260	0%	0%
COS Road Salt	P304-122215-0920	0.64	1242 1248 1254 1260	6.5%	0%
CIPP	030-100314-1330	0.64	1242 1254	4.3%	0%
hydroseed	028-100214-1515	0.59	1248 1260	2.1%	0.02%
WSDOT Salt Brine Soln. FIELD DUP	Replicate #3	0.56	1242 1254	6.3%	0%
hydrostraw (undyed)	201-030915-1258	0.54	1242 1254	11%	0%
WSDOT Deicer	009-091614-1520	0.52	1242 1254 1260	5.8%	0%
Anti Freeze	035-082714-1453	0.45	1254 1260	7.8%	4.3%
yl rd tape	034-091014-1328	0.45	1242	16%	0.3%
syn. motor oil	017-082614-1400	0.44	1242 1260	15%	0%
Class B FFF	007-082814-1401	0.41	1242 1254 1260	0%	2.8%
CaCl Deicer	P302-010716-1030	0.40	1242 1254 1260	7.0%	0%
hand soap	101-101314-1100	0.40	1242 1248	0%	0%
Sand (Road Traction) FIELD DUP	Replicate #6	0.39	1242 1254	14%	0%
dish soap	103-101314-1100	0.38	1242	10%	0%
MgCl Deicer LAB DUP	P301-122215-0830 DUP	0.37	1242 1260	21%	0.9%
WSDOT NaCl salt FIELD DUP	Replicate #5	0.37	1254 1260	8.8%	0%
Hotsy Soap LAB DUP	010-090914-0906 DUP	0.35	1242 1254 1260	0%	0.9%
WSDOT Salt Brine Soln.	P303-010716-0938	0.35	1254 1260	7.1%	0%
Sand (Road Traction) LAB DUP	B6C0145-DUP1	0.34	1254	0.5%	0.3%
hydrant paint	005-100314-1430 DUP	0.33	1242 1254	0%	0%
roundup	014-091814-0945	0.33	1242	0%	0%
Sand (Road Traction) LAB DUP	Replicate #6 DUP	0.32	1242 1248	14%	0%
Sand (Road Traction)	V312-021616-1430	0.32	1254	0.6%	0.2%
WSDOT NaCl salt	V314-022316-1030	0.31	1254	0.4%	0.2%
MgCl Deicer	V309-021016-0910	0.31	1248 1254	0.7%	0.2%
Sand (Road Traction)	P306-122215-0916	0.31	1242 1260	14%	0%

Product	Sample ID	R2	Aroclor(s)	PCB 11	PCB 209
COS Road Salt	V311-021616-1435	0.31	1254	0.4%	0.4%
MgCl Deicer LAB DUP	B6C0121-DUP1	0.31	1248 1254	0.8%	0.3%
COS Road Salt LAB DUP	P311-021616-1435 DUP	0.30	1248	0%	14%
CaCl Deicer	P310-021616-1415	0.29	1248 1260	0%	0%
COS Road Salt LAB DUP	P304-122215-0920 DUP	0.28	1248 1260	19%	0%
WSDOT NaCl salt	P305-010716-0935	0.28	1248 1260	16%	0%
wt rd tape	036-091014-1329	0.24	1242 1248	21%	0%
WSDOT NaCl salt	P314-022316-1030	0.24	1242 1248	0%	0%
tooth paste	105-091514-0900	0.23	1242	0%	0.7%
crosshair	015-091814-0935	0.22	1254 1260	9.6%	0%
WSDOT Salt Brine Soln. LAB DUP	B6C0153-DUP1	0.20	1254	0.7%	0.02%
CaCl Deicer FIELD DUP	Replicate #2	0.18	1260	22%	0%
auto grease	024-082714-1504	0.16	1242 1260	11%	0%
MgCl Deicer	P301-122215-0830	0.15	1254 1260	0%	0%
wood fiber hydromulch (green dyed)	202-030915-1242	0.15	1242	24%	0%
used motor oil	replicate #1	0.13	1260	5.5%	13%
SWARCO Yellow Road Paint	P408-082416-1047	0.13	1242	40%	4.5%
weedar 64 (2,4-D)	012-091814-0930	0.13	1242	0%	0%
CaCl Deicer	V310-021616-1415	0.12	1254	1.0%	0.1%
WSDOT Salt Brine Soln.	V313-022316-1018	0.12	1254	2.9%	0.4%
COS Road Salt	P311-021616-1435	0.11	1248	32%	10%
WSDOT Salt Brine Soln.	P313-022316-1018	0.11	1248	0%	0%
asphalt release agnt.	027-101014-0950	0.11	1242	35%	0%
laundry det.	102-101314-1100	0.10	1242	35%	0.1%
recycled motor oil LAB DUP	016-082714-1459 DUP	0.09	1260	4.9%	0%
recycled motor oil	016-082714-1459	0.08	1254	0%	0%
Hotsy Soap	010-090914-0906	0.08	1260	0%	3.5%
weedar 64 (2,4-D)	012-091814-0930 DUP	0.08	1242	0%	0.5%
Simple Green	011-090914-0908	0.08	1242	24%	2.1%

Product	Sample ID	R2	Aroclor(s)	PCB 11	PCB 209
dust suppressent	023-101014-1035	0.08	1248 1260	2.7%	0.01%
MgCl Deicer	P309-021016-0910	0.07	1248	0%	0%
asphalt release agnt.	027-101014-0950 DUP	0.07	1242	39%	0.4%
Sherwin Williams Yellow Road Paint	P407-082416-1008	0.03	1242	55%	0%
Enis-Flint White Road Paint	P402-091216-1050	0.03	1242	49%	0%
used motor oil	018-082714-1455	0.03	1260	8.3%	0%
Sherwin Williams White Road Paint	Replicate #3.1	0.03	1242	13%	0%
yl rd paint (ennis)	001-091014-1335	NS		6.1%	31%
yl rd paint (ennis)	replicate #2	NS		25%	12%
yl rd paint (sherwin)	002-082514-1039	NS		75%	0.1%
wt rd paint (ennis)	003-091014-1340	NS		14%	49%
wt rd paint (ennis)	replicate #3	NS		18%	44%
wt rd paint (sherwin)	004-082514-1035	NS		26%	0%
wt rd paint LAB DUP	004-082514-1035 DUP	NS		24%	0.9%
hydrant paint	005-100314-1430	NS		21%	2.1%
spray paint (green)	006-082714-1045	NS		5.9%	65%
Deicer	008-091814-0925	NS		1.5%	0%
Deicer	replicate #4	NS		0%	0.1%
portfolio 4f (pesticide)	013-091814-0940	NS		0%	0.4%
gasoline	020-082114-1104	NS		0%	0%
gasoline	020-082114-1104 DUP	NS		0%	0.3%
EADA (dust sup.)	021-100214-1420	NS		28%	0%
SSR1 Asphalt Tack	025-091814-1006	NS		30%	0%
PVC Pipe	029-100314-1330	NS		4.5%	26%
dry yl rd paint	032-091014-1335	NS		7.9%	30%
dry wt rd paint	033-091014-1340	NS		14%	57%
dry wt rd paint LAB DUP	033-091014-1340 DUP	NS		15%	45%
shampoo	104-101314-1100	NS		60%	0%
wood fiber hydromulch (undyed)	203-030915-1241	NS		33%	0.2%

Product	Sample ID	R2	Aroclor(s)	PCB 11	PCB 209
green survey marker (AERVOE)	204-030915-1241	NS		5.4%	61%
green survey marker (AERVOE)	204-030915-1241 DUP	NS		5.6%	69%
MgCl Deicer FIELD DUP	Replicate #1	NS		29%	0%
MgCl Deicer LAB DUP	P309-021016-0910 DUP	NS		0%	24%
Enis-Flint White Road Paint	Replicate #2.1	NS		61%	18%
Sherwin Williams White Road Paint	P403-082416-1030	NS		75%	0%
SWARCO White Road Paint	P404-082416-1110	NS		5.0%	95%
SWARCO White Road Paint	Replicate #4.1	NS		1.7%	97%
Enis-Flint Yellow Road Paint	P406-091216-1040	NS		84%	0%
Enis-Flint Yellow Road Paint	Replicate #6.1	NS		87%	0%
Enis-Flint Yellow Road Paint LAB DUP	Replicate #6 DUP.1	NS		91%	0%
Sherwin Williams Yellow Road Paint	Replicate #7	NS		84%	0%
SWARCO Yellow Road Paint	Replicate #8	NS		89%	4.3%
SWARCO Yellow Road Paint LAB DUP	Replicate #8 DUP	NS		87%	4.4%

NS = not significant

References

Agency for Toxic Substances and Disease Registry (ATSDR), 2000. Toxicological profile for polychlorinated biphenyls (PCBs). U.S. Department of Health and Human Services, Public Health Service,, Atlanta, GA.

Anezaki, K., Nakano, T., 2015. Unintentional PCB in chlorophenylsilanes as a source of contamination in environmental samples. Journal of Hazardous Materials 287, 111-117.

Arnold, T.S., 2017. What's in Your Asphalt? Public Roads 81.

Bedard, D.L., 2003. Polychlorinated biphenyls in aquatic sediments: Environmental fate and outlook for biological treatment. in: Haggblom, M.M., Bossert, I.D. (Eds.). Dehalogenation: Microbial Processes and Environmental Applications. Kluwer Academic Publishers, Boston.
Bedard, D.L., Bailey, J.J., Reiss, B.L., Jerzak, G.V., 2006. Development and characterization of stable sediment-free anaerobic bacterial enrichment cultures that dechlorinate aroclor 1260. Appl Environ Microbiol 72, 2460-2470.
Bedard, D.L., May, R.J., 1996. Characterization of the polychlorinated biphenyls in the sediments of Woods Pond: Evidence for microbial dechlorination of Aroclor 1260 in situ. Environmental Science & Technology 30, 237-245.
Bedard, D.L., Van Dort, H.M., May, R.J., Smullen, L.A., 1997. Enrichment of Microorganisms That Sequentially meta, para-Dechlorin- ate the Residue of Aroclor 1260 in Housatonic River Sediment. Environmental Science & Technology 31, 3308-3313.
Boon, J.P., Eijgenraam, F., Everaarts, J.M., 1989. A Structure-Activity Relationship (SAR) Approach Towards Metabolism of PCBs in Marine Animals from Different Trophic Levels. Mar. Environ. Res. 27, 159-176.
Boon, J.P., vanderMeer, J., Allchin, C.R., Law, R.J., Klunsoyr, J., Leonards, P.E.G., Spliid, H., StorrHansen, E., McKenzie, C., Wells, D.E., 1997. Concentration-dependent changes of PCB patterns in fish-eating mammals: Structural evidence for induction of cytochrome P450. Archives of Environmental Contamination and Toxicology 33, 298-311.
Brown, J.F., Bedard, D.L., Brennan, M.J., Carnahan, J.C., Feng, H., Wagner, R.E., 1987. Polychlorinated biphenyl dechlorination in aquatic sediments. Science 236, 709-712.
Burkhard, L.P., Weininger, D., 1987. DETERMINATION OF POLYCHLORINATED-BIPHENYLS USING MULTIPLE-REGRESSION WITH OUTLIER DETECTION AND ELIMINATION. Analytical Chemistry 59, 1187-1190.
Bzdusek, P.A., Christensen, E.R., Lee, C.M., Pakdeesusuk, U., Freedman, D.C., 2006a. PCB Congeners and Dechlorination in Sediments of Lake Hartwell, South Carolina, Determined from Cores Collected in 1987 and 1998. Environ. Sci. Technol. 40, 109-119.
Bzdusek, P.A., Lu, J., Christensen, E.R., 2006b. PCB Congeners and Dechlorination in Sediment of Sheboygan River, Wisconsin, Determined by Matrix Factorization. Environ. Sci. Technol. 40, 120-129.
Choi, S.D., Baek, S.Y., Chang, Y.S., Wania, F., Ikonomou, M.G., Yoon, Y.J., Park, B.K., Hong, S., 2008. Passive air sampling of polychlorinated biphenyls and organochlorine pesticides at the Korean Arctic and Antarctic research stations: Implications for long-range transport and local pollution. Environmental Science & Technology 42, 7125-7131.
City of Spokane Wastewater Management Department, 2015. PCBs in Municipal Products REVISED. Spokane, WA.
Du, S., Belton, T.J., Rodenburg, L.A., 2008. Source apportionment of polychlorinated biphenyls in the tidal Delaware River. Environmental Science & Technology 42, 4044-4051.
Du, S., Rodenburg, L.A., 2007a. Source Identification of Atmospheric PCBs in Philadelphia/Camden Using Positive Matrix Factorization Followed by the Potential Source Contribution Function. Atmospheric Environment 41, 8596-8608.
Du, S., Wall, S.I., Cacia, D., Rodenburg, L.A., 2009. Passive air sampling for polychlorinated biphenyls in the Philadelphia metropolitan area. Environ Sci Technol 43, 1287-1292.

Du, S.Y., Rodenburg, L.A., 2007b. Source identification of atmospheric PCBs in Philadelphia/Camden using positive matrix factorization followed by the potential source contribution function. Atmospheric Environment 41, 8596-8608.
EPA, U.S., 1999. Method 1668, Revision A: Chlorinated Biphenyl Congeners in Water, Soil, Sediment, and Tissue by HRGC/HRMS. United States Environmental Protection Agency, Washington DC.
Fagervold, S.K., May, H.D., Sowers, K.R., 2007. Microbial reductive dechlorination of Aroclor 1260 in Baltimore Harbor sediment microcosms is catalyzed by three phylotypes within the Phylum *Chloroflexi*. Applied and Environmental Microbiology 73, 3009-3018.
Frame, G.M., 1997. A collaborative study of 209 PCB congeners and 6 Aroclors on 20 different HRGC columns .1. Retention and coelution database. Fresen. J. Anal. Chem. 357, 701-701-713.
Frame, G.M., Cochran, J.W., Boewadt, S.S., 1996. Complete PCB congener distributions for 17 Aroclor mixtures determined by 3 HRGC systems optimized for comprehensive, quantitative, congener-specific analysis. J.High Resol.Chromatogr. 19, 657-668.
Gamboa, J.A., Bohe, A.E., Pasquevich, D.M., 1999. Carbochlorination of TiO2. Thermochim. Acta 334, 131-139.
Gonzalez, J., Feng, L., Sutherland, A., Waller, C., Sok, H., Hesse, R., Rosenfeld, P., 2011. PCBs and dioxins/furans in attic dust collected near former PCB production and secondary copper facilities in Sauget, IL. in: Paoletti, E. (Ed.). Urban Environmental Pollution 2010, pp. 113-125.
Greyell, C., Williston, D., 2018. Green River PCB Equipment Blank Study Data Report. King County Water and Land Resources Division, Seattle, WA.
Guo, J., Capozzi, S.L., Kraeutler, T.M., Rodenburg, L.A., 2014. Global Distribution and Local Impacts of Inadvertently Generated Polychlorinated Biphenyls in Pigments. Environmental Science & Technology 48, 8573-8580.
Herkert, N.J., Jahnke, J.C., Hornbuckle, K.C., 2018. Emissions of Tetrachlorobiphenyls (PCBs 47, 51, and 68) from Polymer Resin on Kitchen Cabinets as a Non-Aroclor Source to Residential Air. Environmental Science & Technology 52, 5154-5160.
Hermanson, M.H., Hann, R., Johnson, G.W., 2016. Polychlorinated Biphenyls in Tree Bark near Former Manufacturing and Incineration Facilities in Sauget, Illinois, United States. Environmental Science & Technology 50, 6207-6215.
Hu, D., Hornbuckle, K.C., 2009. Inadvertent Polychlorinated Biphenyls in Commercial Paint Pigments. Environmental Science & Technology 44, 2822-2827.
Karakas, F., Imamoglu, I., Gedik, K., 2017. Positive Matrix Factorization dynamics in fingerprinting: A comparative study of PMF2 and EPA-PMF3 for source apportionment of sediment polychlorinated biphenyls. Environmental Pollution 220, 20-28.
King, T.L., Yeats, P., Hellou, J., Niven, S., 2002. Tracing the source of 3,3'-dichlorobiphenyl found in samples collected in and around Halifax Harbour. Marine Pollution Bulletin 44, 590-596.
Litten, S., Fowler, B.I., Luszniak, D., 2002. Identification of a novel PCB source through analysis of 209 PCB congeners by US EPA modified method 1668. Chemosphere 46, 1457-1459.
Lubliner, B., 2012. Evaluation of Stormwater Suspended Particulate Matter Samplers. Toxics Studies Unit Environmental Assessment Program Washington State Department of Ecology,, Olympia, WA, p. 70 pp.
Magar, V.S., Johnson, G.W., Brenner, R.C., Quensen, J.F., Foote, E.A., Durell, G., Ickes, J.A., McCarthy, C.P., 2005. Long-term Recovery of PCB-Contaminated Sediments at the Lake

Hartwell Superfund Site: PCB Dechlorination. 1. End-Member Characteristics. Environ. Sci. Technol. 39, 3538-3547.
Paatero, P., Tapper, U., 1994. Positive Matrix Factorization - a Nonnegative Factor Model with Optimal Utilization of Error-Estimates of Data Values. Environmetrics 5, 111-126.
Perdih, A., Jan, J., 1994. FORMATION OF POLYCHLOROBIPHENYLS IN SILICONE-RUBBER. Chemosphere 28, 2197-2202.
Praipipat, P., Meng, Q., Miskewitz, R.J., Rodenburg, L.A., 2017. Source Apportionment of Atmospheric Polychlorinated Biphenyls in New Jersey 1997−2011. Environmental Science & Technology 51, 1195–1202.
Praipipat, P., Rodenburg, L.A., Cavallo, G.J., 2013. Source Apportionment of Polychlorinated Biphenyls in the Sediments of the Delaware River. Environ. Sci. Technol. 47, 4277−4283.
Rodenburg, L.A., 2019. Spokane River Regional PMF Analysis -- Blank Influence Analysis. Spokane River Regional Toxics Task Force, Spokane, WA, p. 27 pp.
Rodenburg, L.A., Delistraty, D., Meng, Q., 2015a. Polychlorinated Biphenyl Congener Patterns in Fish near the Hanford Site (Washington State, USA). Environmental Science & Technology 49, 2767-2775.
Rodenburg, L.A., Delistraty, D.A., 2019. Alterations in fingerprints of polychlorinated biphenyls in benthic biota at the Portland Harbor Superfund Site (Oregon, USA) suggest metabolism. Chemosphere 223, 74-82.
Rodenburg, L.A., Du, S., Fennell, D.E., Cavallo, G.J., 2010a. Evidence for Widespread Dechlorination of Polychlorinated Biphenyls in Groundwater, Landfills, and Wastewater Collection Systems. Environ. Sci. Technol. 44, 7534-7540.
Rodenburg, L.A., Du, S., Xiao, B., Fennell, D.E., 2011. Source Apportionment of Polychlorinated Biphenyls in the New York/New Jersey Harbor. Chemosphere 83, 792–798.
Rodenburg, L.A., Du, S.Y., Lui, H., Guo, J., Oseagulu, N., Fennell, D.E., 2012. Evidence for Dechlorination of Polychlorinated Biphenyls and Polychlorinated Dibenzo-p-Dioxins and -Furans in Wastewater Collection Systems in the New York Metropolitan Area. Environmental Science & Technology 46, 6612-6620.
Rodenburg, L.A., Guo, J., Christie, R., 2015b. Polychlorinated biphenyls in pigments: inadvertent production and environmental significance. Coloration Technology 131, 353-369.
Rodenburg, L.A., Guo, J., Du, S., Cavallo, G.J., 2010b. Evidence for Unique and Ubiquitous Environmental Sources of 3,3'-dichlorobiphenyl (PCB 11). Environ. Sci. Technol. 44, 2816–2821.
Rodenburg, L.A., Krumins, V., Curran, J.C., 2015c. Microbial Dechlorination of Polychlorinated Biphenyls, Dibenzo-p-dioxins, and -furans at the Portland Harbor Superfund Site, Oregon, USA. Environmental Science & Technology 49, 7227-7235.
Rodenburg, L.A., Leidos, 2017a. Green-Duwamish River Watershed PCB Congener Study: Phase 2 Source Evaluation. Seattle, WA.
Rodenburg, L.A., Leidos, 2017b. Green-Duwamish River Watershed PCB Congener Study: Phase 2. Initial Data Assessment. Department of Ecology, State of Washington,, Bothell, Washington.
Rodenburg, L.A., Meng, Q., 2013. Source Apportionment of Polychlorinated Biphenyls in Chicago Air from 1996 to 2007. Environmental Science & Technology 47, 3774-3780.
Rodenburg, L.A., Ralston, D.K., 2017. Historical sources of polychlorinated biphenyls to the sediment of the New York/New Jersey Harbor. Chemosphere 169, 450-459.

Rodenburg, L.A., Winstanley, I., Wallin, J.M., 2019. Source Apportionment of Polychlorinated Biphenyls in Atmospheric Deposition in the Seattle, WA, USA Area Measured with Method 1668. Archives of Environmental Contamination and Toxicology 77, 188-196.
Rushneck, D.R., Beliveau, A., Fowler, B., Hamilton, C., Hoover, D., Kaye, K., Berg, M., Smith, T., Telliard, W.A., Roman, H., Ruder, E., Ryan, L., 2004. Concentrations of dioxin-like PCB congeners in unweathered Aroclors by HRGC/HRMS using EPA Method 1668A. Chemosphere 54, 79-87.
Saba, T., Su, S., 2013. Tracking polychlorinated biphenyls (PCBs) congener patterns in Newark Bay surface sediment using principal component analysis (PCA) and positive matrix factorization (PMF). Journal of Hazardous Materials 260, 634-643.
Soonthornnonda, P., Zou, Y.H., Christensen, E.R., Li, A., 2011. PCBs in Great Lakes sediments, determined by positive matrix factorization. J. Gt. Lakes Res. 37, 54-63.
Stone, A., 2014. Polychlorinated Biphenyls (PCBs) in General Consumer Products. Hazardous Waste and Toxics Reduction Program, Washington State Department of Ecology, Olympia, WA.
Stratton, C.L., Sosebee, J.B., 1976. PCB and PCT Contamination of the Environment near Sites of Manufacture and Use. Environ. Sci. Technol. 10, 1229-1233.
Swackhamer, D.L., Armstrong, D.E., 1988. HORIZONTAL AND VERTICAL-DISTRIBUTION OF PCBS IN SOUTHERN LAKE-MICHIGAN SEDIMENTS AND THE EFFECT OF WAUKEGAN HARBOR AS A POINT-SOURCE. J. Gt. Lakes Res. 14, 277-290.
U. S. Environmental Protection Agency, 2018. Preventing and Detecting PCB Contamination in Used Oil.
Uchimiya, M., Arai, M., Takeda, S., Hosono, S., Masunaga, S., 2011. Deciphering localized dioxins and PCBs contamination in Japanese sediments using Positive Matrix Factorization. Abstracts of Papers of the American Chemical Society 242.
Verbrugge, D.A., Othoudt, R.A., Grzyb, K.R., Hoke, R.A., Drake, J.B., Giesy, J.P., Anderson, D., 1991. CONCENTRATIONS OF INORGANIC AND ORGANIC CONTAMINANTS IN SEDIMENTS OF 6 HARBORS ON THE NORTH-AMERICAN GREAT-LAKES. Chemosphere 22, 809-820.
Wong, S., Era-Miller, B., 2019. Quality Assurance Project Plan: Measuring PCBs in Biofilm, Sediment, and Invertebrates in the Spokane River: Screening Study. Washington State Department of Ecology, Olympia, WA.
Zhang, M.L., Harrington, P.D., 2015. Simultaneous quantification of Aroclor mixtures in soil samples by gas chromatography/mass spectrometry with solid phase microextraction using partial least-squares regression. Chemosphere 118, 187-193.

CURRICULUM VITAE

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EDUCATION

Ph.D. 1999, The Johns Hopkins University, Department of Geography and Environmental Engineering

B.A. 1991, Wittenberg University, Springfield, OH, Chemistry

PROFESSIONAL EXPERIENCE

2017-present	Professor, Rutgers University, Department of Environmental Sciences
2018-present	Graduate program director, Environmental Science
2012-2018	Undergraduate Program Director, Environmental Science (~140 students)
2010-2017	Associate Professor, Rutgers University, Department of Environmental Sciences
2004-2010	Assistant Professor, Rutgers University, Department of Environmental Sciences
2002-2004	Assistant Research Professor, Rutgers University, Department of Environmental Sciences
2001-2002	Laboratory Researcher I, Rutgers University, Department of Environmental Sciences
1998-2001	Camille and Henry Dreyfus Post-Doctoral Fellow in Environmental Chemistry, Rutgers University, Department of Environmental Sciences
1991-1993	Quality Assurance Chemist, Hoechst-Roussel Pharmaceuticals Inc., Somerville, NJ

RESEARCH INTERESTS

Fate of anthropogenic chemicals, particularly PCBs and other semivolatile organic contaminants (SOCs), in water, air, sediments, and biota. Source apportionment of contaminants, management and analysis of large data sets.

HONORS AND AWARDS

Excellence in Review Award from *Environmental Science and Technology* 2014
Camille and Henry Dreyfus Foundation Post-Doctoral Fellowship in Environmental Chemistry
ACS Environmental Division Graduate Student Paper Award 1998
ACS Environmental Division Graduate Student Award 1998
Graduate Student Fellowship, National Science Foundation, 1994-1997
Dean's Fellowship, Johns Hopkins University, Whiting School of Engineering, 1993, 1998
National Merit Scholar, 1987-1991
Graduated Summa Cum Laude from Wittenberg University

PROFESSIONAL AFFILIATIONS

American Chemical Society, Environmental Chemistry Division (ACS)
Society of Environmental Toxicology and Chemistry (SETAC)
Association of Environmental Engineering and Science Professors (AEESP)
Association for Women in Science (AWIS)
Environmental Sciences Affiliate of the New York Academy of Sciences

EDUCATIONAL ACTIVITIES

Primary teaching

2015-present	11:375:197 *Environmental Science Literacy* (house course for the Environmental Science LLC, Douglass Project for women in STEM)	Instructor
2011- present	11:375:340 *Environmental Applications of Organic Chemistry*	Instructor
2001- 2013	11:375:310 *Analytical Environmental Chemistry Laboratory*	Instructor
2000 - present	16:375:522 *Environmental Organic Chemistry*	Instructor

Other teaching

2010-present	01:556:130 Introduction to Scientific Research (ISR)	Research mentor
2012	11:015:103 *Portals to Academic Study Success*	Instructor
2010-2011	11:375:432 *Readings in Environmental Science* (house course for the Douglass Project for women in STEM)	Co-instructor (50%)
2009	16:375:540 *Atmospheric Chemistry*	Instructor
2007	11:375:423/523 *Environmental Fate And Transport*	Co-instructor (50%)
2006	375:454 *Soil Biological Processes*, cross-listed with 375:573 *Soil Ecosystem Processes*	Co-instructor (40%)
2005 – 2006	01:160:200 *Introduction to Research in Chemistry*	Research mentor
1998	*Chemistry of Environmental Issues* (John Hopkins University)	Teaching assistant

MEDIA COVERAGE

ABC News Good Morning America: Is the Color Yellow Dangerous? (interview about PCBs in pigments). 2/23/2014
Scientific American: "Yellow Pigments in Clothing and Paper Contain Long-Banned Chemical" 2/20/2014
Yahoo.com: "PCBs banned for decades but still lurking in some yellow products" 2/25/2014
Newsmax.com "Many Yellow Items Still Contain Banned PCB Chemical, Study Says." 2/21/2014
Environmental Health News: "Yellow pigments in clothing, paper contain long-banned PCB." 2/20/2014
Food Packaging Forum: "PCB-11 detected in clothing and paper samples." 2/21/2014
Environmental Health Perspectives: "Nonlegacy PCBs: Pigment Manufacturing By-Products Get a Second Look." Volume 121, Issue 3, Pages A87-A93. March 2013.

IMPACTS

The State of Washington in 2013 passed legislation (bill 6086) that requires the state to purchase only products that do not contain PCBs. This legislation is aimed in large part at PCBs in pigments, and my work in this area raised awareness and indirectly led to this legislation.

SERVICE

Mentoring

Mentoring committee member for Benjamin Lintner (Assistant Professor) and Jeffra Schaefer (Assistant Research Professor) in the Department of Environmental Science, Rutgers

Founder, *Beautiful Untenured Female Faculty* (BUFF), a peer-to-peer networking group for female faculty at SEBS

Working with High School students on various projects for science fairs, including the Partners in Science program (Liberty Science Center); North Jersey Regional Science Fair; a competition at Monmouth University; and the Young Science Achievers Program. Eleven students mentored so far (2006-present)

Mentored more than 50 undergraduate interns

Professional Societies

Session Chair (with Nicole Fahrenfeld). "Advances in Understanding PPCP Fate in Wastewater Collection & Treatment Systems." American Chemical Society 252nd National Meeting, August 21-25, 2016, Philadelphia, PA.

Member of the 2005 SETAC North America Annual Meeting Program Committee

Session Chair (with Miriam Diamond). "Urban Contaminants: Sources, Composition, Fate from a Multimedia Perspective." SETAC North America 28th Annual Meeting, November 11-15, 2007, Milwaukee, WI.

Session Chair (with DE Fennell) "Fate of Persistent Organic Pollutants in Urban Systems." Division of Environmental Chemistry, 234th American Chemical Society (ACS) National Meeting, August 19-23, 2007, Boston, MA.

University

Search committee, TT appointment in Environmental Microbiology, 2015-2016
Strategic Planning Committee for Douglass Residential College, 2015
Douglass Project STEM Summer Stipend selection committee, 2015
Undergraduate Program Director, Environmental Sciences, 2012-present
Department of Environmental Sciences, Equipment Committee, 2014-2017
Graduate Program in Environmental Sciences, Admissions Committee, 2012-2015
New Brunswick Faculty Council, 2009-2012
Search committee, broad faculty announcement in Environmental Sciences, 2008-2010
Chair, Environmental Sciences Graduate Program Curriculum Committee, 2006-2009
Department of Environmental Sciences Space Committee, 2006-2009
Dean's Ad-Hoc Committee on Childcare, 2005

National Panels

Member, Science and Technical Advisory Committee (STAC), New York/New Jersey Harbor & Estuary Program. 2017-present

Science Advisor, *Made Safe* (http://madesafe.org/), formerly *Non-Toxic Certified*, 2015-present
Reviewer - Green-Duwamish River Watershed PCB Congener Study: Phase 1, 2015
Advisor to the Spokane River Regional Toxics Taskforce, Spokane, WA, 2012-present
Served as an expert witness for the State of Washington (Department of Ecology) at the August 2012 meeting of the Environmental Council of States. I presented a short lecture on the problem of inadvertent production of PCBs in pigments.
Member of Expert Panel advising the Delaware River Basin Commission on establishment of a TMDL for PCBs in the Delaware River 2001-2009

Other
Proposal reviewer for the Hudson River Foundation: Hudson River Fund and Mark Bain Graduate Fellowships
Reviewer for the Arctic Monitoring and Assessment Programme (AMAP) review of Non-Aroclor and Byproduct PCBs 2016
Faculty Advisor, Futurology Club, 2015-2016
Author of Wikipedia entry on Diarylide Pigment
Proposal reviewer, National Science Foundation, Petroleum Research Fund, and U.S. Civilian Research and Development Foundation (CRDF).
Reviewer for *Environmental Science and Technology, Atmospheric Environment, Environmental Engineering and Science, Journal of the Air & Waste Management Association, Industrial and Engineering Chemistry Research, Water Air and Soil Pollution,* and *Science of the Total Environment.*
Poster session organizer, Gordon Conference on Environmental Sciences: Water, 2000.

PUBLICATIONS
Peer-Reviewed (* - author is a current or former student of mine; § work performed as an undergraduate intern)

1. **Rodenburg, LA**; Winstanley, I; Wallin JM. Source Apportionment of Polychlorinated Biphenyls in Atmospheric Deposition in the Seattle, WA, USA area measured with Method 1668. *Archives of Environmental Contamination and Toxicology*. **2019**, 77, 188–196.
2. **Rodenburg, LA**; Delistraty, DA. Alterations in Fingerprints of Polychlorinated Biphenyls in Benthic Biota at the Portland Harbor Superfund Site (Oregon, USA) Suggest Metabolism. *Chemosphere*. **2019**, *223*, 74-82.
3. Capozzi, SL*; Jing, R; **Rodenburg, LA**; Kjellerup, BV. Positive Matrix Factorization analysis shows dechlorination of polychlorinated biphenyls during domestic wastewater collection and treatment. *Chemosphere*. **2019**, *216*, 289-296.
4. Krumins, V; Sun, W; Guo, J*; Capozzi, S*; Fennell, DE; **Rodenburg LA**. Sewer Sediment Bacterial Communities Suggest Potential to Transform Persistent Organic Pollutants. *Water Environ. Res.* **2018,** *90(12)*, 2022-2029.
5. Capozzi, SL*; **Rodenburg, LA**; Krumins, V; Fennell, DE; Mack, EE. Using positive matrix factorization to investigate microbial dehalogenation of chlorinated benzenes in groundwater at a historically contaminated site. *Chemosphere* **2018**, *211*, 515-523.

6. **Rodenburg, LA**; Dewani, Y*; Haggblom, MM; Kerkhof, LJ; Fennell, DE. Forensic Analysis of Polychlorinated Dibenzo-p-Dioxin and –Furan Fingerprints to Elucidate Dechlorination Pathways. *Environ. Sci. Technol.* **2017,** *51*, 10485-10493.
7. Praipipat, P*; Meng, QY; Miskewitz, RJ; **Rodenburg, LA**. Source Apportionment of Atmospheric Polychlorinated Biphenyls in New Jersey 1997- 2011. *Environ. Sci. Technol.* **2017**, *51*, 1195-1202.
8. **Rodenburg, LA**; Ralston, DK. Historical sources of polychlorinated biphenyls to the sediment of the New York/New Jersey Harbor. *Chemosphere*. **2017,** *169*, 450-459.
9. **Rodenburg, LA**; Krumins, V; Curran, JC. Microbial dechlorination of polychlorinated biphenyls, dibenzo-p-dioxins, and -furans at the Portland Harbor superfund site, Oregon, USA. *Environ. Sci. Technol.* **2015** *49*, 7227−7235.
10. **Rodenburg, LA**; Guo J*; Christie, RM. Polychlorinated biphenyls (PCBs) in pigments: inadvertent production and environmental significance. *Coloration Technology*. **2015,** *131*, 353–369. **Feature Article**
11. **Rodenburg, LA**; Delistraty, D; Meng, Q. Polychlorinated biphenyl congener patterns in fish near the Hanford Site (Washington State, USA). *Environ. Sci. Technol.* **2015**, *49*, 2767–2775.
12. Japhe, T., Zhdanova, K., **Rodenburg, L**., Roberson, L., Navarro, AE. Factors affecting the Biosorption of 2-Chlorophenol using spent tea leaf wastes as adsorbents. *J. J Environ. Sci.*, **2015**, *1 (2):* 010.
13. Xiong, Y; Krogmann, U; Mainelis, G; **Rodenburg, LA**; Andrews, CJ. Indoor air quality in green buildings: A case-study in a residential high-rise building in the northeastern United States. *Journal Of Environmental Science And Health, Part A.* **2014**, *50(3)*, 225-242.
14. Guo, J*; Capozzi, SL*; Kraeutler, TM*§; Rodenburg, LA. Global distribution and local impacts of inadvertently generated polychlorinated biphenyls in pigments. *Environ. Sci. Technol.* **2014**, *48*, 8573-8580.
15. Zhen, H.; Du, S*; **Rodenburg, L.A.**; Mainelis, G.; Fennel, D.E. Reductive Dechlorination of 1,2,3,7,8-Pentachlorodibenzo-p-dioxin and Aroclor 1260, 1254 and 1242 by a Mixed Culture Containing *Dehalococcoides mccartyi* strain 195. *Water Research*. **2014**, *52*, 51-62.
16. **Rodenburg, LA**; Meng, Q; Yee, D.; Greenfield, BK. Evidence for photolytic and microbial debromination of brominated diphenyl ether flame retardants in San Francisco Bay sediment. *Chemosphere*. **2014**, *106*, 36-43.
17. Praipipat, P.*; **Rodenburg, L.A.**; Cavallo, G.J. Source Apportionment of Polychlorinated Biphenyls in the sediments of the Delaware River. *Environ. Sci. Technol.* **2013**, *47* (9), 4277–4283.
18. **Rodenburg, L.A.**; Meng, Q. Source Apportionment of Polychlorinated Biphenyls in Chicago Air from 1996-2007. *Environ. Sci. Technol.* **2013**, *47 (8)*, 3774–3780.
19. Liu, H.; Park, J-W.; Fennell, D. E.; **Rodenburg, L. A.**; Verta, M.; Häggblom, M.M. Microbial Reductive Dechlorination of Weathered Polychlorinated Dibenzofurans in Kymijoki Sediment Mesocosms. *Chemosphere*. **2013**, *92(2)*, 212-221.
20. Sandy, A.L.*; Guo, J.*; Miskewitz, R.J.; McGillis, W.R.; **Rodenburg, L.A.** Mass transfer coefficients for volatilization of polychlorinated biphenyls from the Hudson River, New York measured using micrometeorological approaches. *Chemosphere*. **2012**, *90(5)*, 1637-1643.
21. **Rodenburg, L.A.**; Du, S.*; Lui, H.; Guo, J.*; Oseagulu, N.* §; and Fennell, D. E. Evidence for dechlorination of polychlorinated biphenyls and polychlorinated dibenzo-p-dioxins and –

furans in wastewater collection systems in the New York metropolitan area. *Environ. Sci. Technol.* **2012,** *46*, 6612–6620.

22. Sandy, A.L.*; Guo, J.*; Miskewitz, R.J.; McGillis, W.R.; **Rodenburg, L.A.** Fluxes of polychlorinated biphenyls volatilizing from the Hudson River, New York measured using micrometeorological approaches. *Environ. Sci. Technol.* **2012**, *46*, 885-891.
23. **Rodenburg, L.A.**; Du, S.*; Xiao, B.; Fennell, D.E. Source Apportionment of Polychlorinated Biphenyls in the New York/New Jersey Harbor. *Chemosphere*. **2011**, *83*, 792–798.
24. Park, J-W.; Krumins, V.; Kjellerup, B.V.; Fennell, D. E.; **Rodenburg, L.A**.; Sowers, K.R.; Kerkhof, L.J.; Häggblom, M. M. The effect of co-substrate activation on indigenous and bioaugmented PCB dechlorinating bacterial communities in sediment microcosms. *Appl. Microbiol. Biotechnol.* **2011**, *89*, 2005-2017.
25. **Rodenburg, L.A.**; Fennell, D.E.; Du, S.*; Cavallo, G.J. Evidence for Widespread Dechlorination of Polychlorinated Biphenyls in Groundwater, Landfills, And Wastewater Collection Systems. *Environ. Sci. Technol.* **2010**, *44*, 7534-7540.
26. Cwiertny, D.; Arnold, W.A.; Kohn, T.; **Rodenburg, L.A.**; Roberts, A.L. Reactivity of Alkyl Polyhalides toward Granular Iron: Development of QSARs and Reactivity Cross Correlations for Reductive Dehalogenation. *Environ. Sci. Technol.* **2010,** *44*, 7928–7936.
27. **Rodenburg, L.A.**; Valle, S. N.; Panero, M. A.; Munoz, G. R.; Shor, L. M. Mass Balances on Selected Polycyclic Aromatic Hydrocarbons (PAHs) in the New York/New Jersey Harbor. *Journal of Environmental Quality*. **2010**, *39*, 642-653.
28. **Rodenburg, L.A.**; Guo*, J.; Du*, S.; Cavallo, G.J. Evidence for Unique and Ubiquitous Environmental Sources of 3,3'-dichlorobiphenyl (PCB 11). *Environ. Sci. Technol.* **2010**, *44*, 2816–2821. *DOI: 10.1021/es901155h*
29. Krumins, V.; Park, J.W.; Son, E.K.; **Rodenburg, L.A.;** Kerkhof, L.J.; Haggblom, M.M.; Fennell, D.E. PCB Dechlorination Enhancement in Anacostia River Sediment. *Water Research.* **2009,** *43 (18)*, 4549-4558.
30. Du*, S; Wall*, SJ; Cacia*§, D; **Rodenburg, LA.** Passive Air Sampling for Polychlorinated Biphenyls in the Philadelphia, USA Metropolitan Area. *Environ. Sci. Technol.* **2009**, *43*, 1287-1292.
31. Du*, S; Belton, T. J.; **Rodenburg, L.A.** Source Apportionment of PCBs in the Tidal Delaware River. *Environ. Sci. Technol.* **2008**, *42*, 4044–4051.
32. Zarnadze*, A.; **Rodenburg, L.A.** Water Column Concentrations and Partitioning of Polybrominated Diphenyl Ethers in the New York/New Jersey Harbor, USA. *Environmental Toxicology and Chemistry*. **2008**, *27 (8)*, 1636–1642. DOI: 10.1897/07-619
33. Polidori, A.; Turpin, B. J.; Davidson, C. I.; **Rodenburg, L. A.**; Maimone, F. Organic $PM_{2.5}$: Fractionation By Polarity, FTIR Spectroscopy, And OM/OC Ratio For The Pittsburgh Aerosol. *Aerosol Science and Technology*. **2008**, *42(3)*, 233-246.
34. Yan, S.; **Rodenburg, L. A.**; Dachs, J.; Eisenreich, S. J. Seasonal air-water exchange fluxes of polychlorinated biphenyls in the Hudson River Estuary. *Environmental Pollution*. **2008**, *152*, 443-451. doi:10.1016/j.envpol.2007.06.074
35. Du*, S.; **Rodenburg, L. A.** Source Identification of Atmospheric PCBs in Philadelphia/Camden Using Positive Matrix Factorization Followed by the Potential Source Contribution Function. *Atmospheric Environment.* **2007**, *41*, 8596–8608.

36. Asher, B. J.; Wong, C. S.; **Rodenburg, L. A.** Chiral Source Apportionment of Polychlorinated Biphenyls To The Hudson River Estuary Atmosphere And Food Web. *Environ. Sci. Technol.* **2007**, *41*, 6163-6169.
37. Rowe*, A. A.; **Totten, L. A.**; Cavallo, G. J.; Yagecic, J. R. Watershed Processing of Atmospheric Polychlorinated Biphenyl Inputs. *Environ. Sci. Technol.* **2007,** *41*, 2331-2337.
38. Rowe*, A. A.; **Totten, L. A.**; Xie, M.; Fikslin, T. J.; Eisenreich, S. J. Air-water exchange of polychlorinated biphenyls in the Delaware River. *Environ. Sci. Technol.* **2007**, *41*, 1152-1158.
39. **Totten, L. A**.; Stenchikov, G. L.; Gigliotti, C. L.; Lahoti, N.; Eisenreich, SJ. Measurement and Modeling of Urban Atmospheric PCB Concentrations On A Small (8 km) Spatial Scale. *Atmospheric Environment*. **2006**, *40 (40)*, 7940-7952.
40. Yi, S-M; **Totten, L.A.;** Thota*, S.; Yan, S.; Offenberg, J. H.; Eisenreich, S.J.; Graney, J; Holsen, T.M. Atmospheric Dry Deposition of Trace Elements Measured Around the Urban and Industrially Impacted NY-NJ Harbor. *Atmospheric Environment.* **2006,** *40*, 6626–6637.
41. **Totten, L.A.**; Panangadan*, M.; Eisenreich, S.J.; Cavallo, G.J.; Fikslin, T.J. Direct and Indirect Atmospheric Deposition of PCBs to the Delaware River Watershed. *Environ. Sci. Technol.* **2006**, *40 (7)*, 2171-2176.
42. Gigliotti, C.L.; **Totten**, L.A.; Offenberg, J.H.; Dachs, J.; Reinfelder, J.R.; Nelson, E.D.; Glenn, T.R. IV; Eisenreich, S.J. Atmospheric Concentrations and Deposition of PAHs to the Hudson River Estuary. *Environ. Sci. Technol.* **2005**, *39*, 5550-5559.
43. Gioia, R.; Offenberg, J. H.; Gigliotti, C.L.; **Totten, L.A.**; Du*, S.; Eisenreich, S.J. Atmospheric Concentrations and Deposition of Organochlorine Pesticides in the US Mid-Atlantic Region. *Atmospheric Environment.* **2005**, *39 (12)*, 2309-2322.
44. **Totten, L. A.**; Gigliotti, C. L.; VanRy, D. A.; Offenberg, J. H.; Nelson, E. D.; Dachs, J.; Reinfelder, J. R.; Eisenreich, S. J. Atmospheric Concentrations and Deposition of PCBs to the Hudson River Estuary. *Environ. Sci. Technol.* **2004**, *38*, 2568-2573.
45. Koelliker, Y.; **Totten, L. A.**; Gigliotti, C. L.; Offenberg, J. H.; Reinfelder, J. R.; Zhuang, Y.; Eisenreich, S. J. Atmospheric Wet Deposition of Total Phosphorus in New Jersey. *Water, Air, and Soil Pollution*. **2004**, *154 (1-4)*, 139-150.
46. **Totten, L. A.**; Gigliotti, C. L.; Offenberg, J. H.; Baker, J. E.; Eisenreich, S. J. Re-evaluation of Air-Water Exchange Fluxes of PCBs in Green Bay and Southern Lake Michigan. *Environ. Sci. Technol.* **2003,** *37*, 1739-1743.
47. Van Ry, D. A.; Gigliotti, C. L.; Glenn, T. R. IV; Nelson, E. D.; **Totten, L. A.**; Eisenreich, S. J. Wet Deposition of Polychlorinated Biphenyls in Urban and Background Areas of the Mid-Atlantic States. *Environ. Sci. Technol.* **2002**, *36*, 3201-3209.
48. Dachs, J.; Glenn, T. R.; Gigliotti, C. L.; Brunciak, P.; **Totten, L. A.**; Nelson, E. D.; Franz, T. P.; Eisenreich, S. J. Processes driving the short-term variability of polycyclic aromatic hydrocarbons in the Baltimore and northern Chesapeake Bay atmosphere, USA. *Atmospheric Environment* **2002**, *36*, 2281-2295.
49. Naumova, Y. Y.; Eisenreich, S. J.; Turpin, B. J.; Weisel, C. P.; Morandi, M. T.; Colome, S. D.; **Totten, L. A.**; Stock, T. H.; Winer, A. M.; Alimokhtari, S.; Kwon, J.; Shendell, D.; Jones, J.; Maberti, S.; Wall, S. J. Polycyclic aromatic hydrocarbons in the indoor and outdoor air of three cities in the US. *Environ. Sci. Technol.* **2002**, *36*, 2552-2559.
50. **Totten, L. A.**; Eisenreich, S. J.; Brunciak, P. Evidence for destruction of PCBs by the OH radical in urban atmospheres. *Chemosphere* **2002**, *47*, 735-746.

51. Gigliotti, C. L.; Brunciak, P. A.; Dachs, J.; IV, G. T. R.; Nelson, E. D.; **Totten, L. A.**; Eisenreich, S. J. Air-Water Exchange of Polycyclic Aromatic Hydrocarbons in the NY-NJ Harbor Estuary. *Environ. Toxicol. Chem.* **2001**, *21*, 235-244.
52. **Totten, L. A.**; Brunciak, P. A.; Gigliotti, C. L.; Dachs, J.; Glenn. T. R., IV; Nelson, E. D.; Eisenreich, S. J. Dynamic Air-Water Exchange of Polychlorinated Biphenyls in the NY-NJ Harbor Estuary**.** *Environ. Sci. Technol.* **2001**, *35*, 3834-3840.
53. **Totten, L. A.**; Roberts, A. L. Calculated one- and two-electron reduction potentials and related molecular descriptors for reduction of alkyl and vinyl halides in water. *Crit. Rev. Environ. Sci. Technol.* **2001**, *31*, 175-221.
54. **Totten, L. A.**; Roberts, A. L.; Jans, U. Alkyl bromides as probes of reductive dehalogenation: Reactions of stereochemical probes with zero-valent metals. *Environ. Sci. Technol.* **2001**, *35*, 2268-2274.
55. Roberts, A. L.; **Totten, L. A.**; Arnold, W. A.; Burris, D. R.; Campbell, T. J. Reductive elimination of chlorinated ethylenes by zero-valent metals. *Environ. Sci. Technol.* **1996**, *30*, 2654-2659.

Other

1. **Rodenburg, LA** and Leidos. Green-Duwamish River Watershed Addendum to PCB Congener Study: Phase 2 Source Evaluation Report. Prepared for State of Washington Department of Ecology Toxics Cleanup Program. 2018.
2. **Rodenburg,** LA and Leidos. Green-Duwamish River Watershed PCB Congener Study: Phase 2 Initial Data Assessment. Prepared for State of Washington Department of Ecology Toxics Cleanup Program. 2017.
3. **Rodenburg, LA** and Leidos. Green-Duwamish River Watershed PCB Congener Study: Phase 2 Source Evaluation. Prepared for State of Washington Department of Ecology Toxics Cleanup Program. 2017.
4. Du*, S.; **Rodenburg, LA**. "Measurement and Modeling of Semivolatile Organic Compounds in Local Atmospheres." In: *Biophysico-Chemical Processes of Anthropogenic Organic Compounds in Environmental Systems.* Baoshan Xing, Ed. Pp. 149-184, 2010.
5. **Totten, LA.** "The Importance of Atmospheric Interactions to PCB cycling in the Hudson and Delaware River Estuaries." In: *PCBs: Human and Environmental Disposition and Toxicology.* LG Hansen and LW Robertson, Eds. University of Illinois Press, Chicago, IL, pp. 51-59, 2008.
6. **Rodenburg, LA.** "Appendix B: Summary Of Mass Balances On Selected Polycyclic Aromatic Hydrocarbons (PAHs) In The NY/NJ Harbor Estuary." In: *Pollution Prevention And Management Strategies For Polycyclic Aromatic Hydrocarbons In The New York/New Jersey Harbor.* Report by the New York Academy of Sciences, pp. 139-141, 2007. Available at: http://www.nyas.org/programs/harbor.asp
7. **Totten, L. A.** "Present-Day Sources and Sinks for Polychlorinated Biphenyls (PCBs) in the Lower Hudson River Estuary," In: *Pollution Prevention And Management Strategies For Polychlorinated Biphenyls In The New York/New Jersey Harbor.* Report by the New York Academy of Sciences, pp. 84-96, 2005. Available at: http://www.nyas.org/programs/harbor.asp
8. **Totten, L. A.;** Eisenreich, S.J.; Gigliotti, C. L.; Dachs, J.; VanRy, D.A.; Yan, S.; Aucott, M. "Atmosphere Deposition of PCBs and PAHs to the New York/New Jersey Harbor Estuary."

In: *The Hudson River Estuary*. J. Levinton and J. R. Waldman, Eds. Cambridge University Press, New York, pp. 398-412, 2006.

9. Baker, J. E.; **Totten, L. A.**; Gigliotti, C. L.; Offenberg, J. H.; Eisenreich, S. J.; Bamford, H. A.; Huie, R. E.; Poster, D. L. Response to Comment on "Reevaluation of Air-Water Exchange Fluxes of PCBs in Green Bay and Southern Lake Michigan." *Environ. Sci. Technol*. **2004,** *38*, 1629-1632.
10. **Totten, L. A.**; Assaf-Anid, N. M. "Abiotic Dehalogenation by Metals." In: *Dehalogenation: Microbial Processes and Environmental Application*. Haggblom, M.M.; Bossert, I. D., Eds. Kluwer: New York, 2002.
11. Eisenreich, S. J.; Gigliotti, C.L.; Brunciak, P. A.; Dachs, J.; Glenn IV, T. R.; Nelson, E. D.; **Totten, L. A.**; VanRy, D.A. "Persistent Organic Pollutants in the Coastal Atmosphere of the Mid-Atlantic States-USA." In: *Persistent Bioaccumulative Toxic Organic Compounds*. R. Lipnick, Ed. American Chemical Society Symposium Series: Washington, D. C., 2000.

PRESENTATIONS

Invited lectures

Rodenburg, LA. PCBs: An Update. Webinar presented September 25, 2017 for the Office of Continuing Professional Education. Available online at: youtube.com

Rodenburg, LA. Why are PCBs and PCDD/Fs dechlorinated by bacteria in some places but not others? Oral presentation. SETAC 38th Annual Meeting in North America, Minneapolis, MN, November 12-16, 2017.

Rodenburg, LA. Green-Duwamish River Watershed PCB Congener Study: Phase 2 Initial Data Assessment. Webinar for the Spokane River Toxics Taskforce. April 26, 2017.

Rodenburg, LA. Green-Duwamish River Watershed PCB Congener Study: Phase 2 Initial Data Assessment. Green-Duwamish Watershed Pollutant Loading Assessment Technical Advisory Committee. Tukwila, WA. March 15, 2017.

Rodenburg, LA. Green-Duwamish River Watershed PCB Congener Study: Phase 2 Initial Data Assessment. US EPA Region 10 and Washington State Department of Ecology. Seattle, WA. March 14, 2017.

Rodenburg, LA. Environmental Data Mining, or How to do Research with No Money. Special seminar, University of Maryland College Park, Department of Civil and Environmental Engineering. December 7, 2015.

Rodenburg, LA. Environmental Data Mining, or How to do Research with No Money. Special seminar, The Johns Hopkins University, Department of Geography and Environmental Engineering. December 8, 2015.

Rodenburg, LA. Microbial Dechlorination of PCBs—it's not just for sediments any more. 250th ACS National Meeting, Boston, MA, August 16-20, 2015.

Rodenburg, LA. Identifying non-Aroclor PCB sources through fingerprinting. Spokane River Regional Toxics Taskforce PCB Workshop. January 12-13, 2015, Spokane, WA.

Rodenburg, LA. Fingerprinting And Source Apportionment Of PCBs And BDEs. Eighth International Conference on Remediation and Management of Contaminated Sediments (Battelle), January 12-15, 2015, New Orleans, LA.

Rodenburg, LA., Krumins, V.; Crowe-Curran, J. Dechlorination of PCBs in the groundwater of the Portland Harbor. Teleconference presentation to Region 10 EPA. January 5, 2015.

Rodenburg, LA. Identifying non-Aroclor PCB sources through fingerprinting. 8th International PCB Workshop, October 5-9, 2014, Woods Hole, MA.

Guo, J.*; Praipipat, P.*; **Rodenburg, LA.** PCBs in pigments, inks, and dyes: Documenting the problem. 17th Annual Green Chemistry & Engineering Conference (American Chemical Society Green Chemistry Institute). June 19, 2013.

Rodenburg, LA. PCBs in consumer products, or how to do research with no money. Oral presentation, Department of Civil and Environmental Engineering, Temple University. March 22, 2013. Philadelphia, PA.

Rodenburg, LA. Stormwater PCBs: Tales from two urban estuaries. Oral presentation at Spokane River Regional Toxics Task Force. June 5-6, 2012. Spokane, WA.

Rodenburg, LA. Microbial dechlorination of persistent organic pollutants in sewers. Oral presentation, Department of Civil and Environmental Engineering, University of Houston. July 9, 2012. Houston, TX.

Rodenburg, LA. Dechlorination of PCBs and dioxins in sewers: Applications to the Passaic River. Special seminar, Montclair State University. March 21, 2012. Montclair, NJ.

Rodenburg, LA; Cacia, DM. Are urban atmospheric PCB concentrations going down? Oral presentation at the 242nd ACS National Meeting, August 28-September 1, 2011, Denver, CO.

Rodenburg, LA; Du, S; Oseagulu, NU; Guo, J; Fennell, DE. Evidence for dechlorination of PCBs and PCDD/Fs in sewers. Oral presentation at the 242nd ACS National Meeting, August 28-September 1, 2011, Denver, CO.

Rodenburg, LA. Water Quality Management in New Jersey's Waterways. Invited seminar, Fermentation Club, Rutgers University, April 3, 2009.

Rodenburg, LA. Diurnal Cycling of Persistent Organic Pollutants in the Atmosphere. Invited seminar, workshop on "Diurnal (Diel) Cycling of Chemical Constituents in Surface Water and Related Media—Scientific and Regulatory Considerations." New Jersey Department of Environmental Protection, December 12, 2008. Trenton, NJ.

Rodenburg, LA. History of contamination in the Hudson River. Invited seminar, Guangzhou Institute of Geochemistry-South China University of Technology Collaborative Workshop. November 13-15, 2008, Guangzhou, PRC.

Rodenburg, LA. PCBs in the Delaware River. Invited seminar, Guangzhou Institute of Geochemistry-South China University of Technology Collaborative Workshop. November 13-15, 2008, Guangzhou, PRC.

Rodenburg, LA. Water Quality Management in New Jersey's Waterways. Invited seminar, School of Environmental Science and Public Health, Wenzhou Medical College. November 18, 2008, Wenzhou, PRC.

Rodenburg, LA. Investigating Atmospheric PCB Source Types, Locations, And Magnitudes In Urban Areas Of New Jersey. Invited presentation, Fifth PCB Workshop: New Knowledge Gained From Old Pollutants. May 18-22, 2008, Iowa City, Iowa.

Rodenburg, LA. The TMDL for PCBs in the Delaware River. Invited seminar, University of Minnesota, Department of Civil and Environmental Engineering, Minneapolis, MN. April 24, 2008.

Rodenburg, LA. The TMDL for PCBs in the Delaware River. Invited seminar, Kettering College of Medical Arts, Kettering, OH. March 27, 2008.

Rodenburg, LA. Atmospheric deposition to the Hudson River. Invited lecture, New York University, November 6, 2007.

Rodenburg, LA; Du, S.; Xiao, B.; Belton, T.; Fennell, D. E. Source Apportionment of Urban PCBs. Platform presentation SETAC 28th Annual Meeting in North America, November 11-15, 2007, Milwaukee, WI.

Totten, LA. PBDEs in the air and water of the NY/NJ Harbor. NJDEP, Trenton, NJ. June 27, 2007.

Totten, LA. Atmospheric Deposition of PCBs to the NY/NJ Harbor and Delaware River. Plenary Presentation, Hudson-Delaware Chapter, SETAC Annual Meeting, Stockton , NJ. April 27-28, 2007.

Totten, LA. PBDEs in the air and water of the NY/NJ Harbor. Hudson River Foundation. May 3, 2006.

Totten, LA. Invited seminar at City College of New York Chemistry Department. September 26, 2005.

Totten, LA. Sampling for semivolatile organic contaminants in environmental compartments. City College of New York, May 5, 2005.

Totten, LA. Invited seminar, NOAA, Ecosystem Processes Division, Howard Laboratories, Highlands, NJ. October 18, 2004.

Totten, LA, AA Rowe, S Yan. Importance of atmospheric interactions to PCB cycling in the Hudson and Delaware River estuaries. Invited oral presentation, American Chemical Society National Meeting, Philadelphia, August 2004.

Totten, LA, AA Rowe, S Yan, SJ Eisenreich. "Importance of atmospheric interactions to PCB cycling in the Hudson and Delaware River Estuaries." 3rd PCB Workshop on Recent Advances in the Environmental Toxicology and Health Effects of PCBs. Champaign, IL, June 13-15, 2004.

Totten, LA. Invited seminar at Swarthmore College, Swarthmore, PA. April 20, 2004.

Totten, LA. "Present-Day Sources and Sinks for Polychlorinated Biphenyls (PCBs) in the Lower Hudson River Estuary." New York Academy of Sciences, New York City, June 2003.

Totten, LA, CL Gigliotti, DA VanRy, ED Nelson, J Dachs, S Yan, JR Reinfelder, and SJ Eisenreich. "PCBs in the Hudson River Estuary: Atmospheric Inputs and Air-water Exchange." New York Academy of Sciences, New York City, November 2002.

Totten, LA, SJ Eisenreich, PA Brunciak. Evidence for Reactions of PCBs with OH Radical In Urban Atmospheres. 3rd SETAC World Congress, Brighton, United Kingdom, 2000.

Totten, LA, AL Roberts. Alkyl Bromides as Mechanistic Probes of Reductive Dehalogenation: Reactions with Zero-Valent Metals. Graduate Student Paper Award Presentation given at the American Chemical Society Annual Meeting, Boston, MA, August 1998.

Presentations at conferences

Capozzi, SL*; Ran, J; **Rodenburg, LA**; Kjellerup, BV; Wilson, EK. Source apportionment of polychlorinated biphenyls in District of Columbia wastewater. Poster. SETAC 38th Annual Meeting in North America, Minneapolis, MN, November 12-16, 2017.

Rodenburg, LA. Opportunities and Challenges of Environmental Data Mining. Oral Presentation. SETAC 38th Annual Meeting in North America, Minneapolis, MN, November 12-16, 2017.

Chitsaz MM*; **Rodenburg, LA**. PCB cycling in stormwater in an urban high desert: Santa Fe, NM. Poster. SETAC 38th Annual Meeting in North America, Minneapolis, MN, November 12-16, 2017.

Capozzi, SL*; **Rodenburg, LA**; Krumins, V; Fennell, DE; Mack, EE. Using Positive Matrix Factorization to Investigate Microbial Dehalogenation of Contaminants in Groundwater. Fourth International Symposium on Bioremediation and Sustainable Environmental Technologies (Battelle). Miami, FL, May 22-25, 2017.

Capozzi, SL*; Ran, J; **Rodenburg, LA**; Kjellerup, BV; Wilson, EK. Source apportionment of polychlorinated biphenyls in District of Columbia wastewater. Poster presentation at the 2017 Chesapeake Potomac Regional Chapter of the Society of Environmental Toxicology and Chemistry, Annapolis, MD, 2017.

Capozzi, SL*; Ran, J; **Rodenburg, LA**; Kjellerup, BV; Wilson, EK. Source apportionment of polychlorinated biphenyls in District of Columbia wastewater. Oral presentation at the 254th American Chemical Society Fall National Meeting & Exposition, Washington, DC, 2017.

Rodenburg LA, and Du, S*. Data Mining and Source Apportionment to Understand Sources and Fate of PCBs. Poster presentation, 9th International PCB Workshop, October 9-13, 2016 Kobe, Japan.

Rodenburg LA, Capozzi, SL*. Data Mining To Answer Complex Environmental Questions. Platform presentation SETAC 37th Annual Meeting in North America, Orlando, FL, November 6-10, 2016.

Rodenburg, LA; Fahrenfeld, N; Blackburne, B§. Factors controlling antibiotics levels in biosolids. Poster presentation SETAC 37th Annual Meeting in North America, Orlando, FL, November 6-10, 2016.

Blackburne, B; Fahrenfeld, N; **Rodenburg, LA**; Factors controlling antibiotics levels in biosolids. American Chemical Society, 252nd National Meeting, August 21-25, 2016, Philadelphia, PA.

Williams, L; Klein A; Milne M; **Rodenburg L**; Fuchs V; Lindsay R. Analyzing Toxics At Parts Per Quadrillion Levels In The Collection System And Treatment Plant Effluent. WEFTEC 2015, September 26-30, 2015, Chicago, IL.

Uram, A§; Guo, J*; **Rodenburg LA,** Capozzi, SL*. Linking contaminated buildings to atmospheric levels of polychlorinated biphenyls. 8th International PCB Workshop, October 5-9, 2014, Woods Hole, MA.

Capozzi, S*; **Rodenburg, LA**; Guo, J*; Murphy, A§; Fennell, DE. Degradation of PCBs by anaerobic bacteria in sewers. 8th International PCB Workshop, October 5-9, 2014, Woods Hole, MA.

Capozzi, S; **Rodenburg, LA**; Guo, J; Murphy, A; Fennell, DE. Degradation of halogenated pollutants by anaerobic bacteria in sewers. Oral presentation, 2013 North America meeting of the Society for Environmental Toxicology and Chemistry (SETAC). November, 2013.

Rodenburg, LA; Guo, J; Capozzi, S; Murphy, A; Fennell, DE. Degradation of flame retardants by anaerobic bacteria in sewers. Poster presentation, 2013 North America meeting of the Society for Environmental Toxicology and Chemistry (SETAC). November, 2013.

Rodenburg, LA; Guo, J; Praipipat, P; Capozzi, S; Murphy, A; Kraeutler, T. PCBs from pigments in children's clothing, crayons, and paper. Poster presentation, 2013 North America meeting of the Society for Environmental Toxicology and Chemistry (SETAC). November, 2013.

Rodenburg, LA; Guo, J; Praipipat, P. PCBs in pigments, inks, and dyes. Oral presentation at the Hudson-Delaware Chapter of SETAC. May 2, 2013, Edison, NJ.

Rodenburg, LA. PCBs in consumer products, or how to do research with no money. Oral presentation, Department of Environmental Science, Rutgers University. April 12, 2013. New Brunswick, NJ.

Rodenburg, LA; Greenfield, BK; Klosterhaus, SL; Yee, D. Photolytic and microbial debromination of BDEs in San Francisco Bay. Oral presentation at the SETAC North America 33nd Annual Meeting, November 2012, Long Beach, CA.

Rodenburg, LA; Guo, J; Du, S; Fikslin, TJ; Cavallo, GJ. Atmospheric deposition of PCBs to the Delaware River. Oral presentation at the SETAC North America 33nd Annual Meeting, November 2012, Long Beach, CA.

Sandy, AL; **Rodenburg, LA**; Miskewitz, RJ; McGillis, WR; Guo, J. Air-water Exchange Fluxes and Mass Transfer Coefficients for PCBs on the Hudson River. Oral presentation at the SETAC North America 32nd Annual Meeting, November 13-17, 2011, Boston, MA.

Rodenburg, LA; Guo, J; Du, S; Oseagulu, NU; Fennell, DE. Are Dioxins Dechlorinated in Sewers? Oral presentation at the SETAC North America 32nd Annual Meeting, November 13-17, 2011, Boston, MA.

Sandy, AL; **Rodenburg, LA**; Guo, J; Miskewitz, RJ; McGillis, WR. Air-water exchange fluxes and mass transfer coefficients for PCBs on the Hudson River. Oral presentation at the 242nd ACS National Meeting, August 28-September 1, 2011, Denver, CO.

Rodenburg, LA; Du, S; Fennell, DE; Cavallo, GJ. Evidence For Extensive Dechlorination Of PCBs In Sewers, Landfills, And Contaminated Groundwater. Oral presentation at Dioxin 2010, 30th International Symposium on Halogenated Persistent Organic Pollutants (POPs), September 12-17, 2010, San Antonio, TX.

Rodenburg, LA; Du, S; Fennell, DE; Cavallo, GJ. Evidence For Extensive Dechlorination Of PCBs In Sewers, Landfills, And Contaminated Groundwater. Oral presentation, 6th International PCB Workshop, May 20-June 2, 2010, Visby, Sweden.

Sandy, AL; Miskewitz, RJ; **Rodenburg, LA.** Direct Measurement of Air/Water Exchange Mass Transfer Coefficients for Polychlorinated Biphenyls using the Micrometeorological Technique. Poster presentation SETAC 30th Annual Meeting in North America, November 19-23, 2009, New Orleans, LA.

Guo, J; Du, S; **Rodenburg, LA**; Cavallo, GJ. Sources of the non-Aroclor congener PCB 11 (3,3'-dichlorobiphenyl) in urban waterways. Poster presentation SETAC 30th Annual Meeting in North America, November 19-23, 2009, New Orleans, LA.

Guo, J; Du, S; **Rodenburg, LA**; Cavallo, GJ. PCB 11 (3,3'-dichlorobiphenyl) in Urban Waterways From Non-Aroclor Sources. Oral presentation American Chemical Society Northeastern Regional Meeting; October 7, 2009; Hartford, CT.

Park, J-W; Krumins, V; Kjellerup, BV; Gillespie, KM; Fennell, DE; Kerkhof, LJ; **Rodenburg, LA**; Sowers, KR; Häggblom, MM. Anaerobic PCB dechlorination by pentachloronitrobenzene-activated Dehalococcoides spp. American Society for Microbiology 2009 General Meeting; May 17 -21, 2009; Philadelphia, PA.

Krumins, V; Park, J-W; Du, S; **Rodenburg, LA**; Häggblom, MM; Kerhkof, LJ; Fennell DE. Reductive Dechlorination of PCBs in Biostimulated Contaminated Sediment. American Society for Microbiology 2009 General Meeting; May 17 -21, 2009; Philadelphia, PA.

Liu, H; Park, J-W; **Rodenburg, LA**; Fennell, DE; Haggblom, MM. Microbial Community Analysis after Dechlorination Stimulating Treatments of Polychlorinated Dibenzo-p-dioxin and Dibenzofuran Contaminated Sediment. American Society for Microbiology 2009 General Meeting; May 17 -21, 2009; Philadelphia, PA.

Rodenburg, LA; Belton, TJ; Du, S; Sandy, AL; Rowe, AA. Atmospheric deposition, source apportionment, and the TMDL for PCBs in the Delaware River, USA. Oral presentation at the 5th SETAC World Congress, 3 - 7 August 2008, Sydney, Australia.

Rodenburg, LA; Krumins, V; Park, J-W; Haggblom, MM; Kerhkof, LJ; Fennell, DE. Stimulation of PCB Dechlorination and Dechlorinators in Contaminanted Sediments. Oral presentation at the 5th SETAC World Congress, 3 - 7 August 2008, Sydney, Australia.

Asher, BJ; Wong, CS; **Rodenburg, LA**. Chiral signatures as a tool for source apportionment of PCBs in the Hudson River Estuary. Platform presentation SETAC 28th Annual Meeting in North America, November 11-15, 2007, Milwaukee, WI.

Rodenburg, LA. PCB sources and fate in New Jersey. Platform presentation SETAC 28th Annual Meeting in North America, November 11-15, 2007, Milwaukee, WI.

Rodenburg, LA; Zarnadze, A. Water column partitioning of BDEs in the New York/New Jersey Harbor. Platform presentation SETAC 28th Annual Meeting in North America, November 11-15, 2007, Milwaukee, WI.

Asher, BJ; Wong, CS; **Totten, LA**. Chiral signatures as a tool for source apportionment of PCBs in the Hudson River Estuary. Oral presentation, American Chemical Society National Meeting, Boston, MA, August 19-23, 2007.

Fennell, DE; Krumins, V; Ravit, B; **Totten, LA**. Bioremediation approaches for PCB- and PCDD/F-contaminated sediments. Oral presentation, American Chemical Society National Meeting, Boston, MA, August 19-23, 2007.

Du, S.; Xiao, B.; Belton, T.; Fennell, D. E.; **Totten, LA.** Source apportionment of PCBs in the Delaware River and NY/NJ Harbor. Oral presentation, American Chemical Society National Meeting, Boston, MA, August 19-23, 2007.

Sandy, A. L.; Du, S.; Kaczorowski, D. M.; **Totten, LA.** Atmospheric PCB sources to the Delaware River. Oral presentation, American Chemical Society National Meeting, Boston, MA, August 19-23, 2007.

Totten, LA; Du, S; Stenchikov, G. Modeling atmospheric POP dynamics in urban systems. Oral presentation, American Chemical Society National Meeting, Boston, MA, August 19-23, 2007.

Xiao, B.; Du, S.; Fennell, D. E.; Totten, L. A. Source apportionment of POPs in the NY/NJ Harbor. Oral presentation, American Chemical Society National Meeting, Boston, MA, August 19-23, 2007.

Zarnadze, A.; Totten, L. A. Brominated diphenyl ethers in the New York/New Jersey Harbor. Oral presentation, American Chemical Society National Meeting, Boston, MA, August 19-23, 2007.

Kaczorowski, DM; Sandy, AL; Wall, SJ; **Totten, LA**. Investigating the correlation of atmospheric polychlorinated biphenyl concentrations with several variables in Camden, NJ. Poster presented at the Hudson-Delaware Chapter of SETAC Annual Meeting. April 26-27, 2007.

Du, S; **Totten, LA**. Source Apportionment of PCBs in the Delaware River Estuary. Oral presentation at the Hudson-Delaware Chapter of SETAC Annual Meeting. April 26-27, 2007.

Sandy, AL; Du, S; **Totten, LA**. Atmospheric deposition sources of PCBs to the Delaware River. Oral presentation at the Hudson-Delaware Chapter of SETAC Annual Meeting. April 26-27, 2007.

Häggblom, M.M.; Fennell, D.E.; Kerkhof, L.J.; Totten, L.A.; Sowers, K.R.; Ahn, Y.-B.; Liu, F.; Liu, H.; Park, J.-W.; Krumins, V. 2006. Quantifying Enhanced Microbial Dehalogenation of Organohalide Mixtures in Contaminated Sediments. Partners in Environmental Technology Technical Symposium & Workshop sponsored by SERDP and ESTCP. November 28-30, 2006. Washington, D.C.

Pagnout C.; Ní Chadhain, S. M.; **Totten, L. A.**; Zylstra, G. J.; Kukor, J. J. Molecular characterization of microbial community shifts occurring in Passaic River sediments during enrichment on biphenyl and monochlorobiphenyls. 5th Tripartite Workshop in Biotechnology and Bioenergy (NJ, USA), April 2007.

Pagnout, C.; Ní Chadhain, S. M.; **Totten, L. A.**; Zylstra, G. J.; Kukor, J.J. Microbial Diversity Shifts in Sediment Enrichment Cultures during the Aerobic Degradation of Biphenyl and Mono-Chlorinated Biphenyls. American Society for Microbiology, General Meeting, Toronto, Canada, May 21-25, 2007.

Fennell, D.E., Liu, F., Son, E.-K., Zarnadze, A., Krogmann, U., **Totten, L.A.** Fate of Brominated Flame Retardants in New Jersey Wastewater Treatment Facilities. Oral presentation at the USDA NEC 1010 Meeting, Ithaca, NY, October 18-19, 2006.

Zarnadze, A.; **Totten, LA**. BDEs in the New York/New Jersey Harbor, USA. Poster presentation at the SETAC 27th Annual Meeting in North America, 5-9 November 2006, Montreal, Canada.

Du, S; **Totten, LA**. PCB sources to the Delaware River, USA. Oral presentation at the SETAC 27th Annual Meeting in North America, 5-9 November 2006, Montreal, Canada.

Totten, LA; Rowe, AA; Panangadan, M. Atmospheric Deposition and Volatilization of PCBs in the tidal Delaware River. Oral presentation at SETAC 26th Annual Meeting in North America, 13-17 November 2005, Baltimore, Maryland, USA.

Du, S; **Totten, LA**. Attempts to Identify Atmospheric PCB sources in the Philadelphia Metro Area. Oral presentation at SETAC 26th Annual Meeting in North America, 13-17 November 2005, Baltimore, Maryland, USA.

Totten, LA. A Mass Balance On PCBs and PAHs in the NY/NJ Harbor Estuary. Oral presentation at SETAC 26th Annual Meeting in North America, 13-17 November 2005, Baltimore, Maryland, USA.

Fennell, DE; Liu, F; Son, E-K; Zarnadze, A; Krogmann, U; **Totten, LA**. Biotransformation of Halogenated Contaminants in Sludges and Enrichments from Municipal Anaerobic

Digesters. Oral presentation at SETAC 26th Annual Meeting in North America, 13-17 November 2005, Baltimore, Maryland, USA.

Asher, B; Wong, C; **Totten, LA**. Source apportionment of chiral PCBs in the Hudson River Estuary. Poster presentation at SETAC 26th Annual Meeting in North America, 13-17 November 2005, Baltimore, Maryland, USA.

Totten, LA; Du, S. Atmospheric PCB Sources in the Philadelphia Metro Area. SETAC Hudson-Delaware Chapter Regional Meeting, April 28, 2005.

Du, S; **Totten, LA** Identifying source areas of PCBs to the Camden/Philadelphia atmosphere. Poster presentation, SETAC 25th Annual Meeting, Portland, OR, November 14-18, 2004.

Rowe, AA; **Totten, LA**; Offenberg, JH; Reinfelder, JR; Eisenreich, SJ. Air-water exchange of polychlorinated biphenyls in the Delaware River Basin. Poster presentation, SETAC 25th Annual Meeting, Portland, OR, November 14-18, 2004.

Rowe, AA; **Totten, LA**; Offenberg, JH; Sommerfield, CK; Du, S; Reinfelder, JR; Eisenreich, SJ. Accumulation of PCBs in sediments of the Delaware River Estuary. Poster presentation, SETAC 25th Annual Meeting, Portland, OR, November 14-18, 2004.

Wall, SJ; **Totten, LA**. A Mobile Platform for Air Toxics Monitoring in New Jersey, USA. Poster presentation, SETAC 25th Annual Meeting, Portland, OR, November 14-18, 2004.

Zarnadze, A; **Totten, LA**; Eisenreich, SJ. Measurements of Polybrominated Diphenyl Ethers (PBDEs) in the air and water of NY/NJ Harbor Estuary. Poster presentation, SETAC 25th Annual Meeting, Portland, OR, November 14-18, 2004.

Totten, LA. Importance of atmospheric interactions to PCB cycling in the Hudson and Delaware River Estuaries. Poster presentation, SETAC 25th Annual Meeting, Portland, OR, November 14-18, 2004.

Totten, LA; Litten, SP. Mass Balance On PCBs and PAHs in the NY/NJ Harbor Estuary. Poster presentation, SETAC 25th Annual Meeting, Portland, OR, November 14-18, 2004.

Zarnadze, A, **LA Totten**. Levels of Polybrominated Diphenyl Ethers (PBDEs) in the Atmosphere of New Jersey, USA. Oral Presentation, Dioxin 2004, Berlin, Germany, September 2004.

Polidori, A, BJ Turpin, HJ Lim, **LA Totten**, C Davidson. Characterization Of The Organic Fraction Of Atmospheric Aerosols. Annual Meeting of the American Association for Aerosol Research, Atlanta, GA, October 2004.

Totten, LA, S Litten. Mass Balances On PCBs and PAHs in the NY/NJ Harbor Estuary. Oral presentation at the 36th Mid-Atlantic Industrial and Hazardous Waste Conference, University of Connecticut, Storrs, CT, October 8-10, 2004.

Zarnadze, A, **LA Totten**, DE Fennell, MP Giacalone, U Krogmann. PBDEs in the NY/NJ Harbor estuary. Poster presentation, American Chemical Society National Meeting, Philadelphia, August 2004.

Rowe, AA, S Du, SJ Eisenreich, JH Offenberg, **LA Totten**, A Zarnadze. Accumulation of PCBs in sediments of the Delaware River Estuary. Oral presentation, American Chemical Society National Meeting, Philadelphia, August 2004.

Rowe, AA.; Eisenreich, SJ.; Offenberg, JH.; **Totten, LA**. "Accumulation of PCBs in sediments of the Delaware River Estuary." Oral Presentation, Society of Toxicology and Chemistry 24th Annual Meeting in North America, Austin, Texas, November **2003**.

Yan, S, **LA Totten**, CL Gigliotti, JH Offenberg, SJ Eisenreich, J Dachs, JR Reinfelder. "Air-water exchange controls phytoplankton PCB concentrations in impacted estuaries."

Society of Toxicology and Chemistry 24th Annual Meeting in North America, Austin, Texas, November **2003**.

Zhuang, Y, KM Ellickson, SJ Eisenreich, **LA Totten**, JR Reinfelder. "Atmospheric deposition and impacts of trace metals and mercury in the New Jersey Atmospheric Deposition Network (NJADN)." Poster, Society of Toxicology and Chemistry 24th Annual Meeting in North America, Austin, Texas, November **2003**.

Zarnadze, A, **LA Totten,** JH Offenberg, CL Gigliotti, SJ Eisenreich. "Measurements of Poly-brominated Diphenyl Ethers (PBDE) in the air and water of Hudson River Estuary." Poster, Society of Toxicology and Chemistry 24th Annual Meeting in North America, Austin, Texas, November **2003**.

Ellickson, KM, Y Zhuang, BJ Turpin, SJ Eisenreich, **LA Totten**, JR Reinfelder. "Source identification of mercury and other trace metals in New Jersey fine particulate matter (PM2.5) and rain." Poster, Society of Toxicology and Chemistry 24th Annual Meeting in North America, Austin, Texas, November **2003**.

Cardona-Marek, T, KM Ellickson, **LA Totten**, JR Reinfelder. "Mercury Cycling in the Estuarine Zones of the Delaware River." Poster, Society of Toxicology and Chemistry 24th Annual Meeting in North America, Austin, Texas, November **2003**.

Totten, LA, JR Reinfelder, CL Gigliotti, DA Van Ry, J Dachs, JH Offenberg, Y Koelliker, M Panangadan, S Yan, Y Zhuang, SM Goodrow, KM Ellickson, R Gioia, and SJ Eisenreich. "Atmospheric Deposition of Organic and Inorganic Contaminants to the New Jersey Meadowlands." Oral presentation, Meadowlands Symposium, New Jersey Meadowlands Commission, Lyndhurst, NJ, October 9 and 10, **2003**.

Totten, LA, S Yan, and CL Gigliotti. "PCBs: The Lower Hudson River Estuary and the New Jersey Atmospheric Deposition Network." Oral presentation, American Chemical Society National Meeting, New York City, September 2003.

Assaf-Anid, NM, M Blenner, **LA Totten**, Y-B Ahn, DE Fennell, and M Haggblom. "Agreement of computational chemistry predictions of reductive dechlorination pathways with experimental microcosm studies." Poster, American Chemical Society National Meeting, New York City, September 2003.

Rowe, AA, SJ Eisenreich, CL Gigliotti, JH Offenberg, and **LA Totten**. "Interactions of atmospheric polychlorinated biphenyls with the Delaware River Estuary." Oral presentation, American Chemical Society National Meeting, New York City, **2003**.

Gigliotti, CL. **LA Totten**, DA VanRy, PA Brunciak, TR Glenn, J Dachs, SJ Eisenreich. "Atmospheric Deposition and Air-Water Exchange of PAHs in the NY/NJ Harbor Estuary." Oral presentation, Society of Environmental Toxicology and Chemistry, 22nd Annual Meeting, Baltimore, Maryland, **2001**.

Totten, LA, CL Gigliotti, DA VanRy, TR Glenn, SJ Eisenreich. "Atmospheric Deposition and Air-water Exchange of Heptachlor in the NY/NJ Harbor Estuary." Oral presentation, Society of Environmental Toxicology and Chemistry, 22nd Annual Meeting, Baltimore, Maryland, **2001**.

Totten, LA, X Liu,DJ Braun, Assaf-Anid, NM. "Use Of Computational Chemistry To Predict Reduction Potentials Of Polychlorinated Biphenyls." Poster, American Chemical Society Annual Meeting, San Diego, CA, April **2001**.

Assaf-Anid, N. Robert Ambrosini, Xuefeng Liu, Lisa Totten. "A Comparison of Computational Chemistry and Bond Contribution Calculations as Tools for Two-electron Redox

Determinations of PCBs." Poster, Society of Environmental Toxicology and Chemistry, 22nd Annual Meeting, Baltimore, Maryland, **2001**.

Totten, LA, CL Gigliotti, DA VanRy, PA Brunciak, TR Glenn, SJ Eisenreich. Atmospheric Deposition and Air-Water Exchange of PCBs in the NY/NJ Harbor Estuary. Poster, Society of Environmental Toxicology and Chemistry, 22nd Annual Meeting, Baltimore, Maryland, **2001**.

Totten, LA, X Liu, DJ Braun, NM Assaf-Anid. "Use Of Computational Chemistry To Predict Reduction Potentials Of Polychlorinated Biphenyls." Poster, American Chemical Society Annual Meeting, San Diego, CA, April **2001**.

Van Ry, DA, TR Glenn, C Schauffele, R Gioia, CL Gigliotti, **LA Totten**, SJ Eisenreich. "Atmospheric PCBs and PAHs from an Urban to a Forested Area in the Mid-Atlantic States." Oral presentation, Society of Environmental Toxicology and Chemistry, 22nd Annual Meeting, Baltimore, Maryland, **2001**.

Assaf-Anid, NM, **LA Totten**, SJ Braun. "Computational chemistry calculations of thermodynamic descriptors for chlorinated aliphatic compounds and PCBs." Poster, Society of Environmental Toxicology and Chemistry National Meeting, Nashville , TN, **2000.**

Braun, DJ, NM Assaf-Anid, **LA Totten**, "Computational Chemistry: A Novel Approach for Redox Potential Calculations." Oral Presentation, The 32nd Annual Mid-Atlantic Industrial and Hazardous Waste Conference, Rensselaer Polytechnic Institute, **2000**.

Cummings, DA, **LA Totten**, T Lectka, AL Roberts. "Computational Methods For Predicting Heats Of Formation Of Halogenated Methyl And Ethyl Radicals." Oral presentation, American Chemical Society Annual Meeting, Anaheim, CA, April **2000**.

Totten, LA, AL Roberts. "Kinetics of inner-sphere reduction reactions of polyhalogenated methanes." Poster, American Chemical Society Annual Meeting, San Francisco, CA, **1997**.

Totten, LA, AL Roberts. "Stereospecificity of vicinal dehalogenation reactions promoted by abiotic reductants." Poster, Environmental Sciences: Water Gordon Research Conference, New Hampton, NH, June **1996**.

Roberts, AL, DR Burris, TJ Campbell, JA Specht, WA Arnold, **LA Totten**. "Influence of electron transfer pathway on products resulting from metal-promoted reduction of chlorinated ethenes." Oral presentation, IBC International Symposium on Biological Dehalogenation, Annapolis, MD, October 18-19, **1995**.

Totten, LA, AL Roberts. "Investigating electron transfer pathways during reductive dehalogenation reactions promoted by zero-valent metals." Oral presentation, American Chemical Society Annual Meeting, Anaheim, CA, April **1995**.

PAST AND CURRENT SUPPORT

NY/NJ Harbor Contamination Assessment and Reduction Project: CARP II. NJDOT. 7/1/2016-6/30-2018. LA Rodenburg and RJ Miskewitz. Subcontract to Rutgers: $190,000. Full grant: $4,000,000 to Monmouth U.

Rutgers University Raritan River Initiative. EPA. 7/1/2012-6/30/2015. CC Obropta, B Ravit, LA Rodenburg. $100,000

Using Sewage to Treat Contaminated Sediment. Rutgers Office of Technology Commercialization. 9/1/2012-8/30/2014. LA Rodenburg, RJ Miskewitz. $50,000.

Where is microbial dehalogenation occurring in the groundwater at Chambers Works? DuPont Corporation. 1/1/2012-12/31/2014. LA Rodenburg, V Krumins. $300,000.

Baseline Assessment of Water and Sediment Quality in the Lower Raritan River. Edison Wetlands Association. 1/1/2011 – 12/31/2012. LA Rodenburg, LJ Kerkhof. $50,000.

Talking Creativity: Conversations between Scientists and Artists. RU FAIR mini-grant proposal. 1/1/2011-6/30/2011. F Olin, LA Rodenburg. $4400.

Continuation of the New Jersey Atmospheric Deposition Network (NJADN). Delaware River Basin Commission. 1/1/2010-6/30/2012. Approx. $100,000 per year. LA Rodenburg.

Quantifying Enhanced Microbial Dehalogenation Impacting the Fate and Transport of Organohalide Mixtures in Contaminated Sediments. SERDP. 3/1/2006-2/28/2010. $1,880,000. MM Haggbloom, DE Fennell, LA Totten, LJ Kerkhof, and K Sowers (UMd).

Measuring Indoor Air Quality in "Green" Hotel Rooms. Hartz Mountain Industries. 1/2009-6/2009. $10,000. LA Rodenburg and J Senick (RU Center for Green Building).

A Gas Chromatograph-Mass Spectrometer (GCMS) for the Analysis of Organic Compounds in Marine and Environmental Samples. Cook/NJAES Intramural Awards Program, Research Infrastructure Awards. 3/10/09-6/30/09. $25,500 EL Sikes, P Falkowski, DE Fennell, W Huang, LA Rodenburg and N Yee.

Measuring Indoor Air Quality in "Green" vs. Conventional Residential Construction. BASF Corporation. 9/2008-3/2009. $3,000. LA Rodenburg and J Senick (RU Center for Green Building).

Graduate student fellowship to Andy L. Sandy. Hudson River Foundation. 9/1/08-8/31/09. $16,000. AL Sandy and LA Rodenburg.

Assessing the Status of Women in Engineering at Rutgers University. Office of the Associate VP for Promotion of Women in Science, Engineering and Mathematics, Rutgers University. 7/1/2008-3/31/2009. $7,950. M Baykal-Gursoy, J Bennett, HM Buettner, L Klein, U Krogmann, M Pelegri, LA Rodenburg, PA Roos.

Volatilization of PCBs from the Tappan Zee region of the Hudson River. NJWRRI. 3/1/2008-2/28/2009. $30,000. LA Rodenburg and RJ Miskewitz.

Continued Air Monitoring for PCBs in the Delaware River Estuary via the NJADN. Delaware River Basin Commission. 6/1/08-12/31/09. $70,000. LA Rodenburg

Passive Air Sampling for PCBs in the Philadelphia Area. Delaware River Basin Commission. 10/1/06-12/31/07. $24,000. LA Totten

Continued Air Monitoring for PCBs in the Delaware River Estuary via the NJADN. Delaware River Basin Commission. 10/1/06-12/31/07. $88,000. LA Totten

Insights into the Cycling of PCBs in the NY/NJ Harbor Estuary from Chiral Analysis. NJDEP. 7/1/2006-6/30/2007. $50,000. LA Totten.

Construction of a Flux Chamber to Determine Air–Water Exchange Mass Transfer Coefficients of Hydrophobic Organic Contaminants. Cook/NJAES Intramural Awards Program, Pre-Tenure Faculty Career Development Awards. 3/10/06-6/30/06. $29,540. LA Totten.

An Accelerated Solvent Extraction (ASE) System for Analysis of Anthropogenic and Natural Chemicals in Environmental Samples and Biota. Cook/NJAES Intramural Awards Program, Research Infrastructure Awards. 3/10/06-6/30/06. $34,620. LA Totten, DE Fennell, MM Haggblom, W Huang, L Kerkhof, C Obropta, EL Sikes, LA White.

Source apportionment of organic contaminants in the NY/NJ Harbor Estuary. Hudson River Foundation. 7/1/2005-12/31/2007. $95,300. LA Totten and DE Fennell.

Source Apportionment of PCBs in the Delaware River Estuary. NJDEP. 7/1/2005-6/30/2006. $65,000. LA Totten.

Impacts of Organic Matter Heterogeneity on Desorption and Availability of Sediment-Bound PCBs. NJWRRI. 3/1/2005-2/28/2006. $30,000. W Huang and LA Totten.

Triple Quadrupole GC/MS For Analysis of Trace Organics in Environmental Matrixes. (Instrumentation Grant). Academic Excellence Fund, Rutgers University. 2004-2005. $175,000. LA Totten, DE Fennell, JR Reinfelder, W Huang, BJ Turpin, RM Sherrell, EL Sikes, LA White.

Graduate Student Fellowship to Archil Zarnadze. Hudson River Foundation. 9/1/04-8/31/05. $16,000. A Zarnadze and LA Totten.

Fate of Brominated Flame Retardants in New Jersey Wastewater Treatment Facilities. NJWRRI. 3/1/2004-2/28/2005. $30,000. DE Fennell, LA Totten and U Krogmann.

Continued Measurement and Modeling of Atmospheric PCBs in the Delaware River Basin. Delaware River Basin Commission, $95,000, 2003-2005

Community Based Air Toxics Monitoring Studies. NJDEP, $272,000, 1/1/2003-12/31/2004. LA Totten.

Emissions And Atmospheric Transport Of PCBs And Hg From Stabilized Harbor Sediments. NJ Marine Sciences Consortium, $219,000, 4/3/2003-6/60/2004. JR Reinfelder, LA Totten, G Stenchikov, GP Korfiatis, RI Hires.

Measurement of Atmospheric PCBs in the Delaware River Basin. Delaware River Basin Commission, $316,000, 2001-2005. LA Totten, JR Reinfelder, SJ Eisenreich.

Measurement of PBDEs in the Air and Water of the Hudson River Estuary. Hudson River Foundation, $176,000, 7/1/2002-6/30/2004. LA Totten, SJ Eisenreich.

Characterizing Organic Fine Particulate Matter (PM2.5) for the Pittsburgh Supersite. Electric Power Research Institute, $50,000, 2002. BJ Turpin, LA Totten.

Atmospheric Dry Particle Deposition of POPs and Trace Metals in an Urban- and Industrially-Impacted Mid-Atlantic Estuary. US EPA, $230,000, 2000-2004. LA Totten, SJ Eisenreich, T Holsen.

Consulting projects

Baron and Budd Law Firm (2017-present): Expert witness in various lawsuits including City of Spokane and State of Washington versus Monsanto.

Washington State Department of Ecology and EPA under subcontract to Leidos (2016): Evaluate And Conduct Factor Analysis On PCB Data From The Green/Duwamish River

County of Spokane, WA under subcontract to Brown and Caldwell (2014): Source apportionment of PCBs and BDEs in the wastewater of Spokane.

New York Academy of Science (2010): Evaluation of on-going sources of organic contaminants to the lower Passaic River.

New York Academy of Science (2005): Mass balance on PAHs in the New York/New Jersey Harbor

New York Academy of Science (2004): Mass balance on PCBs in the New York/New Jersey Harbor

STUDENT ADVISING

PhD students (primary advisor):

Amy A. Rowe, PhD completed 2006. Interactions Of Polychlorinated Biphenyls With The Air, Water, And Sediments Of The Delaware River Estuary. Amy is tenured as the Cooperative Extension Agent in Passaic County for the Rutgers New Jersey Agricultural Experiment Station.

Songyan Du, PhD completed 2008. Source Apportionment and Measurement of PCBs and POPs in NY/NJ Area. Songyan works for the NJ Department of Health measuring PCBs in human blood and other samples.

Archil Zarnadze, PhD completed 2010. Poly-Brominated Diphenyl Ethers (PBDEs) in the Air and Water of the NY/NJ Harbor and in the Air of Philadelphia/Camden Area.

Andy L. Sandy, PhD completed 2010. The Application of a Micrometeorological Technique to Measure Air-Water Exchange of Polychlorinated Biphenyls.

Jia Guo, PhD completed 2013. Fate and Transport of Polychlorinated Biphenyls in the Air, Water, and Sewers of the Delaware River Basin.

Pornsawai Praipipat, PhD 2014. Source Apportionment of Polychlorinated Biphenyls in New Jersey air and Delaware River sediments.

Staci L. Capozzi, PhD completed 2016. Using Positive Matrix Factorization to Investigate Microbial Dechlorination of Contaminants in Groundwater.

MS students (primary advisor):

Dawn Cacia, MS completed 2010. Statistical Analysis of Atmospheric Polychlorinated Biphenyl Concentrations at Two Urban Locations.

Gerald Rustic, MS completed 2011. PAH contamination in the sediments of the Arthur Kill.

Yashika Dewani, MS completed 2016. Dechlorination of Polychlorinated Dibenzo-p-Dioxins in the Watershed of The New York/New Jersey Harbor.

Non-thesis MS students (primary advisor):

Maya Panangadan (MS completed 2004)

Steven J. Wall (MS completed 2006)

Hye-Nah Yoo (MS completed 2015)

Nicholas Morgan (MS completed 2015)

Thesis/Dissertation committees:

Dana Armstrong (PhD expected 2018 in Civil and Environmental Engineering, UMd College Park)

Kelly Francisco (PhD 2016)

Hang Dam (PhD 2016)

Lauren Weisel (MS Marine Science, 2015)

Rouzbeh Tehrani (PhD in Civil and Environmental Engineering 2013, Temple University)
Nathan Howell (PhD in Civil and Environmental Engineering 2012, University of Houston)
Il Kim (PhD 2009)
Derek Wright (PhD 2008)
Lora Smith (PhD 2008)
Samriti Sharma (PhD 2007)
Andrea Polidori (PhD 2005)
Sathyapriya Thota (MS in Civil and Environmental Engineering 2004)
Yan Zhuang (PhD 2004)
Dan Salvito (PhD 2003)
Rosalinda Gioia (MS 2003)
Shu Yan (MS 2003)
Cheng-Wei Fan (PhD 2002)

Undergraduate interns (partial list)
GHC = George H. Cook Honors Thesis
ISR = Intro to Scientific Research course part of the Douglass Project for Women in STEM

Ady Miretsky
Alden Adrion
Alex Anderson (ISR)
Alexis Uram (ISR)
Anthony Murphy (ARESTY and GHC)
Anthony DeCristofano
Anton Woronczuk (ARESTY)
Ashtyn Greenstein (ISR)
Athina Ramadanis
Brittney Blackburne (ISR and GHC)
Chris Schauffele
Daniel Frier
Dawn Cacia
Erin Mayfield
Farah Mahmud
Harini Sadeeshkumar
Huibin Luo (GHC)
Hye Na Yoo
John Lisowski (ARESTY)
Kerry Jade Manzano
Lea Perez (GHC)
Masrur Alam
Matt Columbo
Mindaugus Rimkus
Nicole Oseagulu
Rebekka Reider
Robert Pawle
Sabah Mahmud
Shiqi Wu
Steve Wall
Zachary Bakhtin

High school students (science fair projects and other research):
Thomas Kreisel – triclosan in drinking water – Thomas won the New Jersey Stockholm Junior Water Prize for this research.
William Zupko – trace metals in sediment samples from Woodbridge Creek
Bryan Schwab - brominated flame retardants in indoor and outdoor air
Sarah Tanner – source apportionment of PCBs in the sediment of the NY/NJ Harbor
Mitchell Booth – VOCs emitted from crumb rubber mulch (Liberty Science Center Partners in Science program)
Rachel Ruben – designing a drinking water treatment system for developing countries
Andrew Baskharon – phytoremediation of malathion
Mikel Byers (Nixon-Smiley High School, Nixon, TX) – water quality impacts of hydraulic fracturing
Ricardo Rivera – Biodegradation of BDEs (Liberty Science Center Partners in Science program) 2014

Kartik Bhardwaj – Source apportionment of PCBs in San Francisco Bay (Liberty Science Center Partners in Science program) 2015

Nishita Sinha – migration of fecal coliform out of a novel sand pit toilet in India 2015. This research has earned multiple awards:

- Recipient of the National Stockholm Junior Water Prize (after winning the State competition). The award includes $10,000 and an all-expenses paid trip to the World competition in Stockholm, Sweden.
- Ms. Sinha was selected for the 2016 MIT summer Research Science Academy, a highly selective program
- Arizona State University Walton Sustainability Award
- Theobald Smith Society Award in Microbiology
- National Oceanic and Atmospheric Administration (NOAA) Pulse of the Planet Award
- NJ Water Environment Association Award
- International Sustainable World (Energy, Engineering, and Environment) Project (ISWEEEP) Sustainable World Award
- Honorable mention at the International Sustainable World (Energy, Engineering, and Environment) Project Olympiad in Houston, Texas
- Fourth Place Oral Presenter at the regional Junior Sciences and Humanities Symposium at Rutgers (JSHS)